Final Report

ROBOTICS AND PACKAGING ASSESSMENT FOR THE DISTRIBUTION DIRECTORATE AT WARNER ROBINS AIR FORCE BASE

Prepared by:

Georgia Institute of Technology
Technology Applications Laboratory

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Submitted to:

Warner Robins ALC, USAF

June 30, 1984

GEORGIA INSTITUTE OF TECHNOLOGY

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Atlanta, Georgia 30332

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EXECUTIVE SUMMARY

The Distribution Directorate at Warner Robins AFB, Georgia has taken a leading role in responding to Air Force initiatives to improve productivity at the Air Logistics Centers. This study is the first of its kind conducted by the Air Force focused on distribution operations. The Distribution Directorate at Warner Robins aggressively evaluates and implements emerging technologies to maintain the highest level of service and efficiency. This is evidenced by the state-of-the-art information and control systems utilized in the warehousing complex and the use of advanced technologies such as wire-guided vehicles and bar-code readers.

The maturation of the robotics industry presents the Distribution Directorate with new opportunities to enhance their mission capabilities and service and to reduce costs by improving productivity and efficiency. This report covers a 10-month effort, conducted by the Engineering Experiment Station of the Georgia Institute of Technology in Atlanta, Georgia, to assess the opportunities for the utilization of robotics technology in the Distribution Directorate operations. It offers a framework for analyzing potential applications and further presents cost/benefit feasibility assessment for three systems that were selected from ten identified applications. It also provides specific considerations for both technical and implementation planning for robotic systems.

Over 500 hours were spent on-site by the research project team, collecting detailed information on distribution operations, during the first six months of this project. The information gathered was used to systematically break down the operations from large scale objectives to unique processes performed on materials and finally to common functionality of tasks. This methodical assessment led to the generating of ten potential application areas with varying degrees of technical complexity, ease of installation and required development. Input from Distribution Directorate management personnel was solicited in the form of presentations and discussions on each of these areas to aid in the selection of candidates for further feasibility assessment. One person from AFALC also participated in the selection process.

This report recommends three specific activities to be undertaken for the use of robot sytems in distribution operations:

1. A cost effective installation requiring minimal development to acquire familiarization with robotic systems.

2. A cost effective installation requiring moderate development in an area important to the future use of robotic systems: integration with data processing systems.

3. A long range, focused research effort for the development of robotics capabilities that are critical to the interests of the Distribution Directorate.

Recommendation 1

At the initiation of this project, we had hoped to identify an application requiring minimal development effort and using commercially available products for a task that occurs in multiple locations throughout the Distribution Directorate. This was not to be the case, as the most adaptable system concept occurred in a packaging task that was unique to one isolated operation: that of gyro packing and depacking. However, this application, while isolated at Warner Robins Distribution Directorate, may be highly transferable to similar packaging applications at other Air Logistic Centers. Implementation of this concept could also potentially lead to other packaging applications which require moderate technical development.

Recommendation 2

The feasibility study for the TAALS (Transporting Automatic Addressing and Labeling Systems) automation presents an opportunity (with moderate development effort) to integrate a robotics system with one of the existing Distribution Directorate information systems. The integration of a robotics system with information systems for planning and control will be a major developmental milestone that will maximize the utilization of these systems in the years to come. The TAALS application also leads to the development of capabilities that address the functional requirements of the acquisition and handling of paperwork. This task proliferates throughout the distribution operations and is expected to be retained for the foreseeable future.

Recommendation 3

Sortation is the manual process which is at the central core of the operations of the Distribution Directorate. In a generic sense, sortation is the acquisition, orientation, singulation, and diversion of material to another destination. This process and its functional requirements are discussed in greater detail within the report. To automate this process, given the complexity and the variability of the materials being handled, will require extensive technical development. But, its achievement would have the greatest impact on the overall operations of the Distribution Directorate in the long term. The feasibility study for the sortation task in the Air Freight Terminal presents a unique opportunity to begin developmental efforts on this problem in an environment where the functional requirements are highly contained. Developmental efforts in this area need to be approached in a methodical, building-block fashion in order to achieve their full, long-run potential.

Our recommendations are to proceed with the detailed design and implementation of a robotics system in the most feasible and lowest risk application: that of gyro packaging. Simultaneously, the Air Force should consider an examination of other Air Logistics Centers for transferable applications based on the background presented in this study. The installation for the TAALS automation should be undertaken after experience with robotic systems is achieved in the gyro pack and depack area. This will also allow for detailed consideration of the interfacing requirement with AWS (Automated Warehousing System), the advanced information system to be installed in the near future.

Finally, the Air Force should undertake a long-term, focused, research effort to address the functional requirements of the complex sortation problem. That research should provide stimuli for innovative, novel ideas and should bring these ideas to the proof of concept stage.

We would like to express our appreciation to Mr. Tommy Haskins and Mr. Bob Brown for their cooperation, hospitality, and dedicated assistance in providing access to the facilities, as well as their own time in data collection and forewarding. We also acknowledge their excellent guidance during the course of this project. We further express our appreciation to Colonel H. C. Tygett and Colonel R. E. Beaver for allowing us the opportunity to provide this study. It is our sincere hope that this effort will not be an end in itself but will provide the basis for continued advancements in mission capabilities, service, and productivity for the Distribution Directorate.

1.0 INTRODUCTION

1.1 Motivation for the Project

The Air Force and the Department of Defense have placed a high priority on modernization within their industrial base and within the service depot activities. Since the late 1970s, there has emerged a pressing need to increase productivity and performance through the application of labor saving technologies. "Payoff 80," an Air Force Executive Report issued 1 October 1980, was a major statement of the Air Force's leadership in this regard. The extraordinary pace of technological development and applications of factory automation and robotics in the private industrial sector has further generated intensive examination within the military complexes for potential utilization of these developments at the depot level.

In October 1983, the Department of Defense Depot Robotics Application Workshop was held in Sacramento, California. This event heralded the significance of robotics technology for depot level activities of the Air Force, Army, and Navy. For the first time, robotics practitioners from the private sector and from the depots of all three services focused on a single area of technology and its applications. Acknowledging the considerable annual investment in direct touch labor for depot level activities, the main conclusion of this workshop was that, "The application of labor saving technology is seen as a mandatory adjunct ... to improve performance and the utilization of limited plant, equipment, capital, and human resources."[1]

Even prior to this landmark event, the Warner Robins Distribution Directorate had initiated activities to search for robotics applications within their operations. Priding themselves on their modern facilities and their track record of award-winning, efficient operations, the management of the Distribution Directorate had, for some time, cast a watchful eye on the rapidly developing robotics technology. The Engineering Experiment Station (EES) of the Georgia Institute of Technology has been concurrently active in

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[1] DOD Robotics Application Workshop, Proceedings; Sacramento, California, 4-7 October, 1983.

the research, development, and application of robotics technology. EES has also worked closely with various groups at the Warner Robins Air Logistics Center on projects including basic research, technical assistance for specialized system design, electronic and mechanical redesign, and emerging technology demonstrations and application assessments. As an outgrowth of these relationships and from a desire to maintain a leading role in efficient operations, the Warner Robins Distribution Directorate requested the assistance of EES to take a fresh, broad look at opportunities for utilizing the advanced robotics automation technology.

EES responded by providing a 10-month effort to study the operation of the Distribution Directorate and provide a base-line document for the planning and future implementation of robotics systems. The timely initiation of this project on September 7, 1983, allowed personnel from EES to accompany and jointly represent the interest of the Warner Robins Distribution Directorate management at the DOD Depot Robotics Application Workshop, previously described. At that gathering, it became clear that the EES effort represented, not only the first of its kind conducted for the Air Force focused on distribution operations, but a leading effort in distribution operations among all three services.

As a result of the leadership of the management of the Warner Robins Distribution Directorate and the visibility of this project, at least one other Air Force Air Logistics Center has proposed to undertake a similar study for their distribution operations. This report provides specific considerations for application of robotics systems in distribution operations that will assist and be transferable to the distribution operations of all five Air Logistics Centers. In this regard, the study goes beyond the assessment of implementable applications for the near-term and provides recommendations for long-term, focused development efforts to be undertaken at the Air Force Headquarters level to take full advantage of this new technology.

1.2 Distribution Directorate Operation

The Distribution Directorate at Warner Robins Air Force Base is one of five Air Force Air Logistics Center Distribution complexes. Responsible for the worldwide distribution of aircraft parts and supplies (with a heavy emphasis and specialization in avionics), the complex at Warner Robins AFB ranks among the largest warehousing operations in the United States. The complexity of the operations is compounded by the size and breadth of the facilities (which encompasses over 60 separate warehouse and facility locations, each with a specialization or emphasis in materials), and the many associated support activities which are incidental to the main thrust of the effort (see Table 1). These include container manufacturing, specialized packaging, fuel storage, and data processing. In addition, some functions such as shipping and receiving have been primarily centralized, while other functions such as packaging and data processing are highly distributed throughout the complex.

In the broadest possible overview, the mission of the complex is to receive materials, provide short-term and long-term storage, and to disperse materials according to requests and orders. Materials are received from sources external to the Warner Robins base location, as well as from repair facilities located on the base. Similarly, shipments are made to repair facilities located on the base and to external locations. Some of the operations, which are embodied in the three primary goals of receiving, storage, and shipping, are information processing (both electronic and manual paperwork), depacking and repackaging, sorting, materials transporation (within the warehouse buildings and between buildings), and inspection. A more thorough treatment of the structure of the distribution process is shown in the following outline:

Mission Goals	Operations on Items	Functional Requirements
Receiving	Identification	Recognition
Storage	Acquisition	Information Collection
Shipping	Sorting	Locating
	Transport	Gripping
	Storage	Movement
	Picking (a Sorting Problem)	Placement
	Consolidation (a Sorting Problem)	Planning Process Control
	Packaging and Depacking	Adaptation (Decision Response)
	Dispatch	
	Accounting	

Table 1

FACILITIES ASSIGNED TO THE DISTRIBUTION DIRECTORATE

FAC NUMBER	DESIGNATION
28	Storage, POL Operations
29	Storage
32	Storage, Liquid Oxygen
38	Hydrant Fuel Building
39	Pump Station, Liquid Fuel
50	Storage, Liquid Oxygen
59	Warehouse
70	Pump Station, Liquid Fuel
72	Pump Station, Liquid Fuel
73	Pump Station, Liquid Fuel
127	Air Freight Terminal
139	Shed - Supports AFT
153	POL Operations - Shop & Showers
193	Class A Magazine
194	POL Operations
195	Pump Station, Liquid Fuel
196	POL Operations - Main Offices
209	Class B Magazine
211	Class C Magazine
301	Warehouse
303	Vehicle Fuel Station
306	Storage, Hazardous Material
309	Warehouse
310	Warehouse
311	Storage Igloo
312	Storage Igloo
313	Storage Igloo
320	Shed, Hazardous Material
322	Shed, Hazardous Material
327	Storage, Hazardous Material
328	Storage, Bottled Gases
329	Storage, Bottled Gases
330	Storage, Bottled Gases
331	Storage, Chemicals
334	Shed, Hazardous Material
335	Shed, Hazardous Material
336	Shed, Hazardous Material
337	Shed, Hazardous Material

TABLE 1

FACILITIES ASSIGNED TO THE DISTRIBUTION DIRECTORATE
(Continued)

FAC NUMBER	DESIGNATION
338	Shed, Hazardous Material
339	Shed, Hazardous Material
342	Warehouse
350	Warehouse
351	Warehouse & Box Factory
354	Paint Facility
357	Shop Shelter Locomotive
364	Warehouse
365	CCP Operations
366	Warehouse
367	Warehouse
368	Warehouse
372	Lumber Shed
376	Central Receiving & Shipping
380	Warehouse
385	Warehouse
386	Storage Igloo, CCP
387	Storage Igloo, CCP
388	Storage Igloo, CCP
389	Storage Igloo, CCP
390	Storage Igloo, CCP
391	Storage Igloo, CCP
392	Storage Igloo, CCP
602	Storage, Packing Supplies
606	Crating Shop
641	Warehouse
660	Warehouse

A major perspective to be established for understanding the complexity of the distribution operations is the extreme variability in the sizes and weights of the materials handled, ranging from individual electronic components to fully assembled aircraft components (such as fuel tanks), the high volume of transactions (exceeding 2.45 million per year), and the vast number of individual material movements and flows throughout the complex. It is this complexity which challenged the EES project team in their search for viable robotics applications.

1.3 Research Approach

The first objective of this project was to familiarize the project team with the facilities and operations from an operational perspective, as well as with the task structure within individual building locations. This familiarization was to provide the research team with the background of how business is conducted within the distribution complex, the level of automation currently utilized, and the intensity and types of materials, flows, and transactions. Because of the complexity of the activities, the guidance and assistance of a designated liaison person from the Warner Robins Distribution Directorate was required.

A prioritization of areas of examination was proposed to allocate and optimize the use of the time spent on-site by the project team. Then, detailed examinations of the prioritized areas were undertaken with regard to the operation, worker, task and functional requirement levels. These examinations included the assembly of data to construct materials and information flow charts, the analysis of job activities considering robotic system feasibility criteria, and the work element functional requirements. A thorough treatment of these activities are presented in section 3 of this report.

A preliminary list of potential robotics applications was generated by matching the functional requirements from these detailed examinations to the capabilities of commercially available robotics systems and emerging technological developments. The list of potential applications was reviewed with the management of the Distribution Directorate in order to insure the inclusion of all relevant aspects, to establish an orderly assessment of these applications, and to select from the list those which would be the subject of further feasibility analysis.

The feasibility analyses for the applications selected began with the task's functional requirements and a characterization of the materials and information handled. A system configuration was proposed to address the specifications of these functional requirements. A 10-year life-cycle economic analysis was then conducted with the inclusion of system capital costs, operating costs, support costs, facilities preparation, throughput and performance, and savings benefits. A final assessment was made on the impact of the proposed system on distribution operations including material flows, vulnerability, mission capability, existing data processing systems, and quality. An assessment was also made for the requirements of maintenance, labor training, and labor relations.

Final conclusions and recommendations are presented encompassing the detailed analysis of activities within the distribution complex and specific application feasibility assessment. In addition to those recommendations, substantive information is provided on considerations for the technical design and successful implementation of robotic systems. An update on the state-of-the-art of associated robotic research is also included in the appendices of this report. This information will assist the future efforts of the Distribution Directorate towards utilization of this new and developing technology and achievement of their objectives of service, productivity, and mission capabilities.

2.0 CONSIDERATIONS FOR ROBOTICS SYSTEMS

2.1 The Industry and Its Future

Beginning in the early 1960s, the development of industrial robot technology sprang from one-of-a-kind, custom designed applications of programmable electromechanical devices. Initial installations addressed those applications which were hazardous and/or repetitious. In 1970 there were roughly 200 industrial robots in manufacturing applications in the United States, primarily in the automotive industry. By 1980, this number had grown to over 4,000 installations and robots were considered a viable technology for virtually all industries. The unparalleled growth in capabilities (with simultaneous reductions in cost) of modern computer technology has been the single most important contributor to the recent development of industrial robots.

Today's industrial robot is a technological advancement that bears little resemblance to its humble beginnings as a mechanical device that would respond only to simple input commands. Modern systems utilize advanced sensory devices for feedback and control and are rapidly gaining the ability to adapt to changes in their work environment and modify their actions based on variations in that environment. The key feature, however, which sets robots apart from other specialized machines is the aspect of flexibility which allows them to be quickly and precisely reprogrammed to accomplish multiple tasks.

The Robotics Industries Association has become the primary trade association for this rapidly evolving industry. An evolving, new industrial language, incorporating terminology unique to robots, is evident in the Robotics Industries Association definition of a robot:

> "An industrial robot is a reprogrammable multi-functional manipulator designed to move material, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks."

At the end of this section is a glossary of other robotic terms and definitions.

The future for the robotics industry is exciting, as advances in systems capabilities and applications are achieved daily. Emerging technologies such as machine vision (in two and three dimensions) tactile devices (to provide a sense of touch), and artificial intelligence (expert, adaptive systems) are rapidly being integrated into robotic systems. With over 400 robot manufacturers worldwide, the technical development and applications accomplishments are proliferating. It has been estimated that by 1990 annual sales volumes for robotic systems will exceed two billion dollars per year.

2.2 System Design Aspects

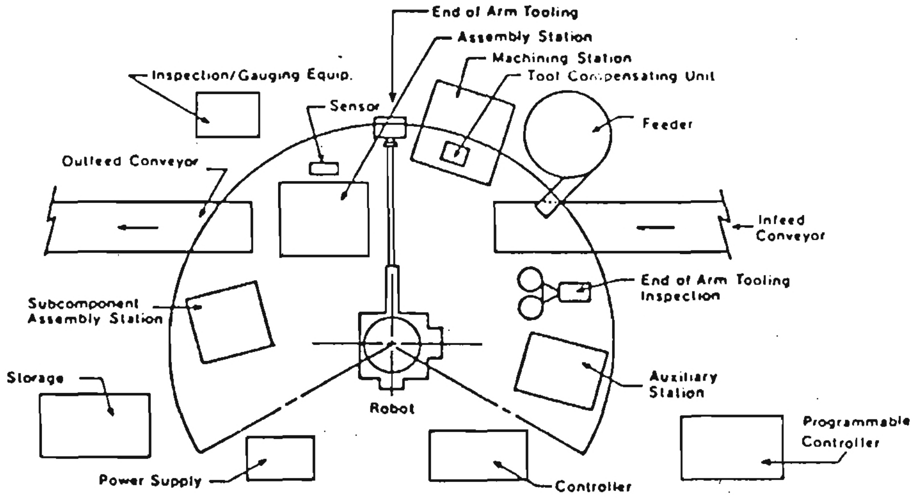
For those contemplating the use of robotics technology in their operations, it is most important to understand that a successful design goes well beyond the robot itself. A systems approach which considers all the components to be integrated in and around the robot's work cell, must be undertaken to achieve the full potential of the installation. In this vein, the robot is but one component in the robotics system. The following sections will describe the components to be considered in the design of the work cell. Figure 1 is an example of items which might appear in a typical robot system work cell.

2.2.1 Robot Configuration

The central component of the system, the robot (often termed the manipulator), can be structured in various configurations according to geometry and axes of motion. The mechanical design of the robot must be selected with regard to the range of tasks to be performed in the particular application. Four general classifications of robot designs have evolved:

- cylindrical coordinate
- spherical coordinate (or polar)
- jointed arm (or revolute)
- rectangular coordinate (or cartesian).

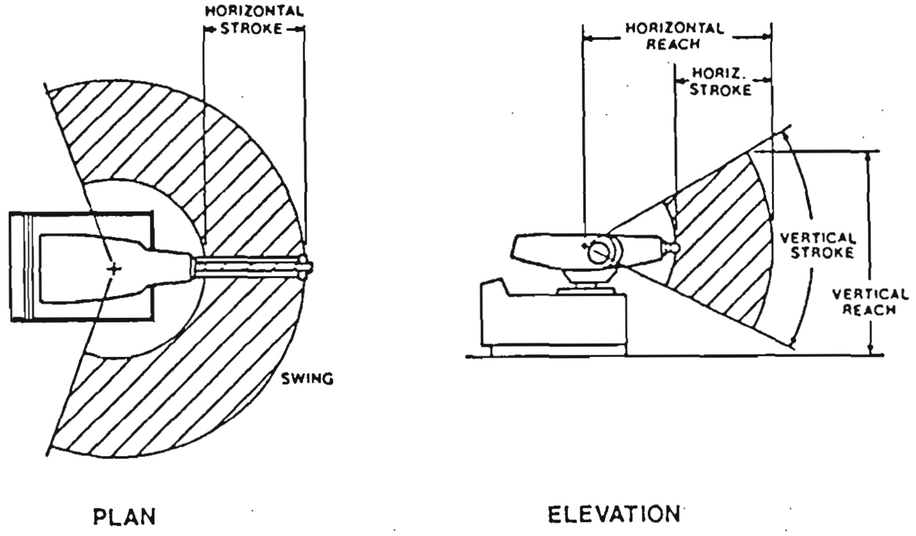
Figures 2 through 5 depict the mechanical configuration and work envelope of these respective types of robots.



POTENTIAL ELEMENTS OF A ROBOT SYSTEM

FIGURE 1

Robotics Basics, Robots 8 Conference, Detroit, Michigan, June 4-7, 1984.



WORK ENVELOPE:
SPHERICAL (POLAR) COORDINATE ROBOT

FIGURE 2

Robotics Basics, Robots 8 Conference, Detroit, Michigan June 4-7, 1984

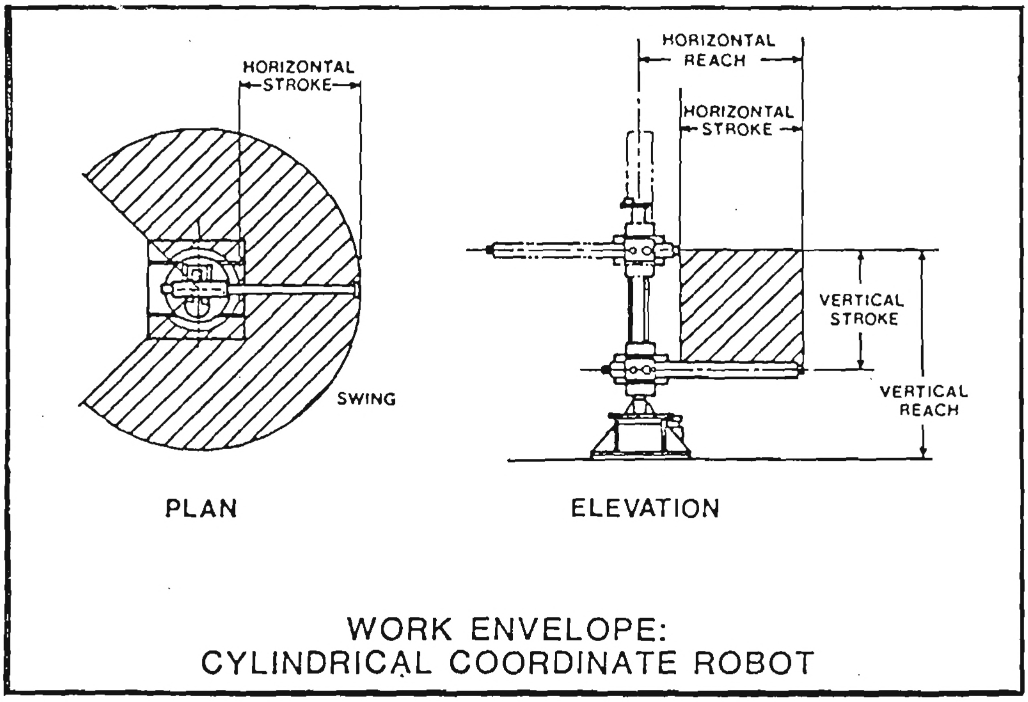
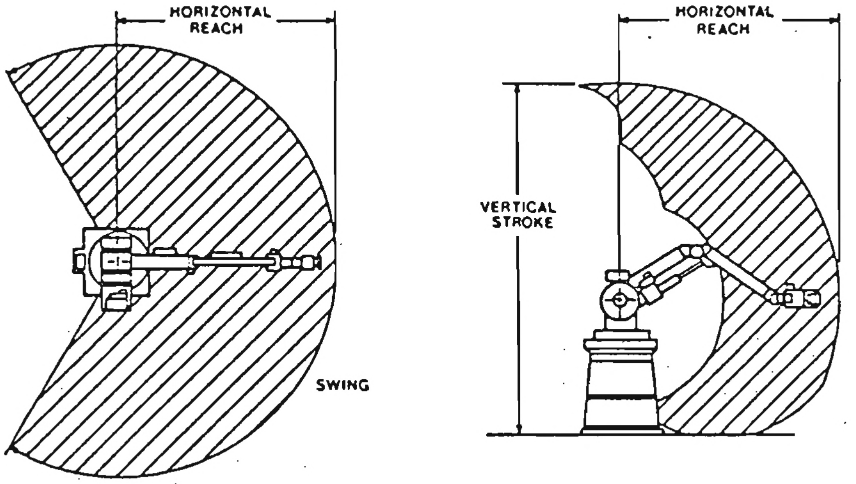


FIGURE 3

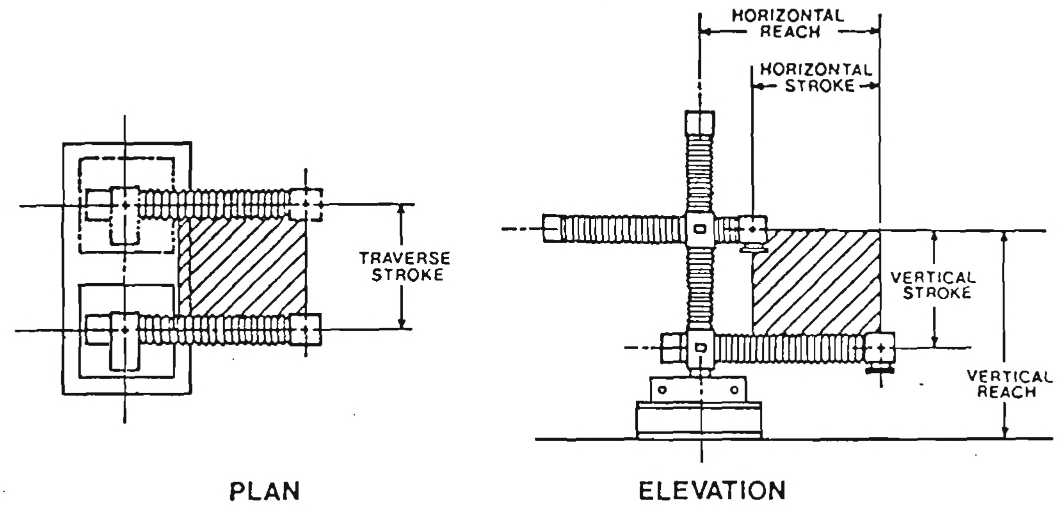
Robotics Basics, Robots 8 Conference, Detroit, Michigan, June 4-7, 1984.



WORK ENVELOPE:
JOINTED ARM (REVOLUTE) ROBOT

FIGURE 4

______ Robotics Basics, Robots 8 Conference, Detroit, Michigan June 4-7, 1984.



WORK ENVELOPE:
RECTANGULAR (CARTESIAN) COORDINATE ROBOT

FIGURE 5

Robotics Basics, Robots 8 Conference, Detroit, Michigan June 4-7, 1984.

Most robots are equipped with additional axes of motion in the wrist assembly. By providing pitch, yaw, and roll capability at the wrist assembly, the robot can place its end-of-arm tooling in an inexhaustable array of positions and orientations.

2.2.2 Robot Drive Power

The drives for moving the robot arms and joints are powered pneumatically, electrically, or by hydraulics. The specific tasks associated with the application require an appropriate selection of the power option. Important considerations are the weight of the payload, velocity of motion, accuracy, noise, and energy consumption. Other aspects to be considered include maintenance, training, parts requirements, potential fluid leakage, and system warm-up requirements.

2.2.3 Robot Controls

The control system requires the most demanding examination when selecting the robot. Control systems range from the simplest mechanical control valves and stops to complex computer systems and associated software. The functional requirements of the tasks associated with the application will dictate the control capabilities required for the robot. The two main categories of robot control systems are differentiated by the manner in which the sequencing of motions is accomplished.

The "point-to-point" systems provide sufficient control to the robot actuators to achieve the traverse from one point to the next without consideration of the actual path followed during the transition. Robots with point-to-point control systems are programmed by storing, in memory, the individual points in space that outline the desired sequence. The robot is then able to repetitively "go through the motions" of moving through this programmed sequence of points.

"Continuous-path" systems store sufficient data in memory to continuously monitor and control the motions of the manipulator on a time basis throughout the program sequence. Process tasks such as spray painting and adhesive application typically require continuous-path control.

Robot control systems can be programmed by physically grasping the manipulator and "leading it through" a pattern of motions while recording either specific points-in-space or the data from continuous sampling of axes motions, depending on the control system type. Alternatively, an electronic teach pendant may be used to drive the robot to specific points and record those points in memory. Programming via data entry on a keyboard is also possible with many control systems. A thorough and detailed knowledge of control systems capabilities, software, and sensors is required to program a robot for a specific task.

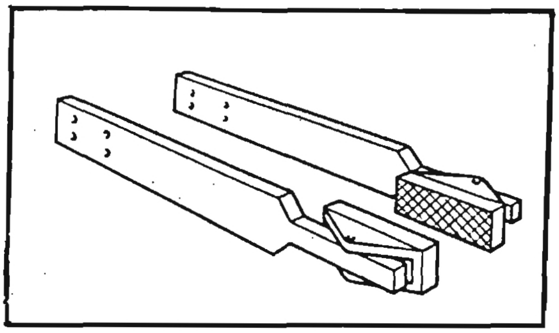
2.2.4 End-of-Arm Tooling

End-of-arm tooling is another major component in the robotic work cell design. Most tooling (also referred to as "end effectors") are used primarily for one of two purposes: to acquire and move materials or to hold tools to perform work on materials. General purpose grippers and specialized assemblies have been designed for tasks ranging from simple materials handling to welding and spray painting. Grippers contain devices that utilize vacuum, magnetic attraction, adhesive, inflatable bladders, and mechanical fingers. They are also available with sensory feedback to determine loads and torques as required. Figures 6 through 10 are representative examples of typical types of robotic end-of-arm tooling. Additional detail on gripper types and designs is presented in the appendices of this report.

2.2.5 Sensors

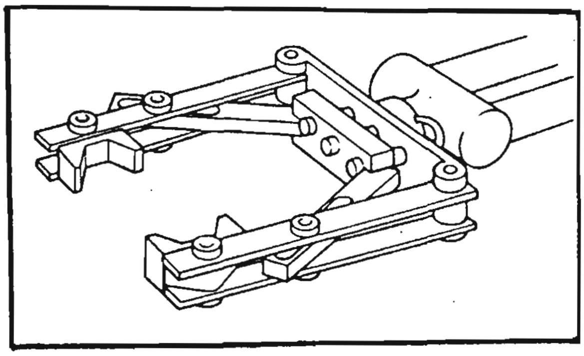
The final major area of consideration for the design of the robotic work cell encompasses the sensors to assist the robot in performing its task. Alone, today's robots are blind, deaf, dumb, and numb. Sensors must be utilized to provide feedback about the status of items in the work cell to the robot controller. Depending on the tasks to be accomplished, the robot may need to know the location and orientation of objects, the "on/off" or "rate" status of associated processes, the distance to items and motion of items, weight, temperature, pressure, volume, shape, and other physical characteristics. One of the most important areas of sensory devices to be included in

END EFFECTOR



Self-Aligning Fingers for
Flat Sided Items

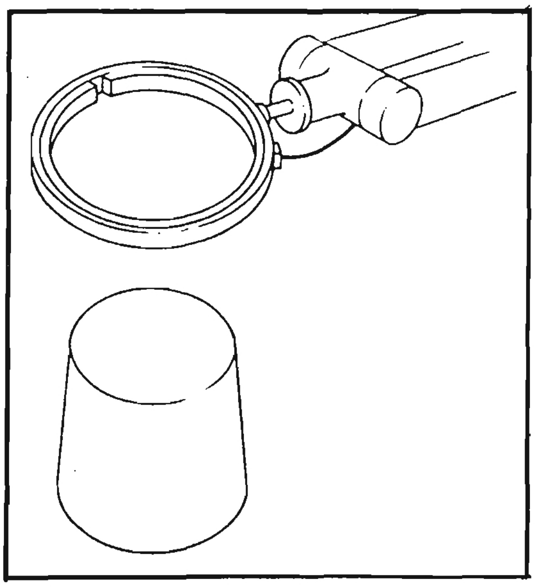
FIGURE 6



Cam-Operated Hand Minimizes
Twisting with Heavy Objects.
Accommodates Only a Narrow
Range of Object Sizes.

FIGURE 7

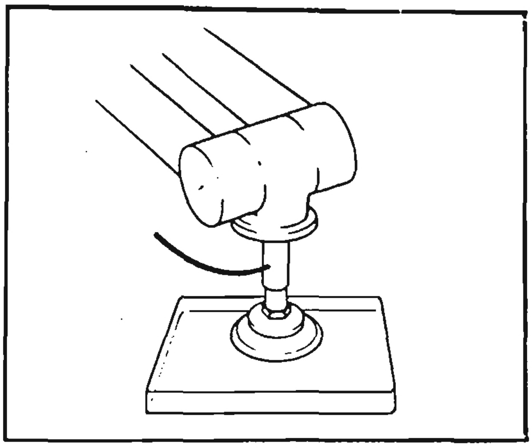
END EFFECTOR



Expansion-Bladder Hand Used on Cylindrical Items. Accommodates Only One Size Item.

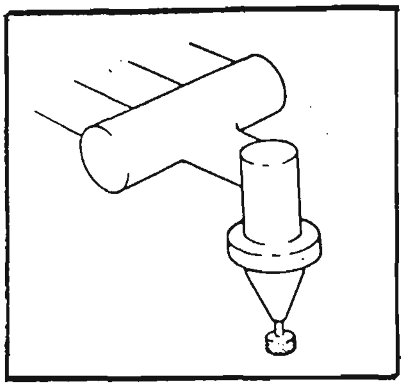
FIGURE 8

END EFFECTOR



Vacuum Cup Hand Used on Flat Surfaces for Light to Moderate Weight Items.

FIGURE 9



Processor Tool Holder can Accommodate Routers, Grinders, Sanders, Sprayers, etc.

FIGURE 10

a robotic work cell are those related to human safety. These may be as simple as emergency stop switches (panic buttons) or as sophisticated as infrared heat detectors. The range of information that must be provided to a robot control system to achieve the desired task can be very large and complex. The design and integration of these sensors may well exceed the cost of the robot itself.

2.3 Financial Justification

Both direct and indirect savings must be included in the cost/benefit analysis to judge the short and long term benefits of a robotic installation. Because of the flexibility of a robotic system (allowing for changes in the task environment at minimal costs) the indirect savings may represent a substantial portion of financial justification for the project. While direct savings in labor is by far the easiest to quantify, the extra effort invested in estimating indirect items (such as improved quality, reduction of scrap, improved scheduling, and increased productivity) to expand the basis for the financial justification is well worth the effort.

The items to be included in the cost of a robotic installation should also include direct and indirect items. The direct quantifiable items are the purchase price of the robot, the cost of specialized sensors, tooling, systems integration, facilities preparations, and systems installation. Indirect items which should be estimated for the analysis are maintenance (including labor and parts supplies), operating power, financing (if required), depreciation of the system, and the cost of training for system programmers and operators.

The direct savings to be established generally include direct labor savings, increased productivity (expanding the direct labor savings), and material savings. Labor savings should be all inclusive in regard to fringe benefits and inflationary effects over the life of the installation. Productivity savings must be estimated by consideration of the effect of the installation on other production flows. Increased throughput for one or more shifts at the robotic installation may cause efficiency improvements in other associated operations. Material savings may accrue because of improved consistency in application of packaging materials, tooling, and other associated items.

Indirect savings often are produced by the orderly structuring of the robotic work cell. These include reduction of material inventory, reductions in damage, reductions in rework and inspection, and elimination of indirect personnel costs such as job training, absenteeism, and hiring costs. These indirect items are best addressed with educated estimates, but nonetheless are pertinent items for consideration.

2.4 Successful Implementation

It has been widely reported in the literature that successful implementation of a robotic system (in particular, the first such installation) requires a substantial amount of human preparatory steps in addition to the technical design and hardware preparation steps. Human preparation includes the participation of production and management personnel in the early stages of the project, as well as a careful selection of project management and responsibility. Experiences of successful first time installations document the beneficial aspects of creating an environment for the "adoption" of the robot project by labor and management alike. Equally documented are the cases of sabotage and failure resulting from job insecurity, management/labor conflict, and hostility towards new technology.

A substantial amount of effort will also need to be allocated to the planning for maintenance and operator training. Reliability and safety issues as well as the achievement of projected savings will depend on a thorough and detailed training program. Additional information regarding human factors considerations can be found in the appendix of this report.

ROBOTIC TERMS AND DEFINITIONS

Actuator - In robots, a device which converts electrical, hydraulic, or pneumatic energy into motion, i.e., cylinders, servo motors, rotary actuators.

Anthropomorphic Robot - A robot with all rotary joints and motions similar to a human's arm.

Artificial Intelligence - The capability of a machine to perform human-like intelligence functions such as learning, adapting, reasoning, and self-correction.

Batch Manufacturing - The production of parts or material in discrete runs, or batches, interspersed with other production operations or runs of other parts or materials.

Cartesian Coordinate - All robot motions travel in right angle lines to each other. There are not radial motions. The profile of its envelope represents a rectangular shape.

Cartesian Coordinate System - A coordinate system whose axes or dimensions are three intersecting perpendicular straight lines and whose origin is the intersection.

Cartesian Coordinate Robot - A robot whose manipulator arm degrees of freedom are defined primarily by cartesian coordinates.

Cell - A manufacturing unit consisting of two or more work stations or machines and the materials transport mechanisms and storage buffers which interconnect them.

Computer-Aided Design (CAD) - The use of a computer to assist in creating or modifying design parameters.

Computer-Aided Manufacturing (CAM) - The use of a computer in the management, control, and operation of manufacturing.

Continuous Path - A servo-driven robot that provides absolute control along an entire path of arm motion, but with certain restrictions in regard to editing and ease of program change.

Controlled Path - A servo-driven robot with a control system which specifies or commands the location and orientation of all robot axes. This allows the robot to move in a straight line between programmed points with the added benefit of real time velocity.

Coordinated Axis Control - Control wherein the axes of the robot arrive at their respective endpoints simultaneously, giving a smooth appearance to the motion.

Cycle - A sequence of operations that is repeated regularly.

Cylindrical Coordinate System - A coordinate system which defines the position of any point in terms of an angular dimension, a radial dimension, and a height from a reference plane. These three dimensions specify a point on a cylinder.

Cylindrical Coordinate Robot - A robot whose manipulator arm degrees of freedom are defined primarily by cylindrical coordinates.

End Effector - The tool attached to the robot manipulator or arm that actually performs the work. Also called end-of-arm tooling.

End of Axis Control - Controlling the delivery of tooling through a path or to a point by driving each axis of robot in sequence. The joints arrive at their preprogrammed positions in a given axis before the next joint sequence is actuated.

External Sensor - A feedback device that is outside the inherent makeup of a robot system or a device used to effect the actions of a robot system that are used to source a signal independent of the robot's internal design.

Feedback - The signal or data sent to the control system from a controlled machine or process to denote its response to the command signal.

Fixed Stop Robot - A robot with stop point control but no trajectory control. That is, each of its axes has a fixed limit at each end of its stroke and cannot stop except at one or the other of these limits.

Memory Capacity - The number of actions that a robot can perform in a program.

Menu - A display of options on a device such as a CRT for user prompting and selection.

Minor Axes (motions) - The axes may be described as the number of independent attitudes the wrist can orient the attached end-effector, relative to the mounting point of the wrist assembly on the arm.

Mobile Robot - A robot mounted on a movable platform.

Off-Line Programming - Defining the sequences and conditions of actions on a computer system that is independent of the robot's "on board" control. The prepackaged program is loaded into the robot's controller for subsequent automatic action of the manipulator.

Operating Range - The reach capability of a robot. Also called work envelope.

Payload - Maximum weight carried at normal speed. Also called workload.

Pick-and-Place Robot - A simple robot with usually 2-4 axes of motion and little or no trajectory control.

Pitch - The angular rotation of a moving body about an axis perpendicular to its direction of motion and in the same plane as its top side.

Point-to-Point Control - A control scheme whereby the inputs or commands specify only a limited number of points along a desired path of motion. The control system determines the intervening path segments.

Processor - A unit in the computer or robot controller which scans all the inputs and outputs in a predetermined order. The processor monitors the status of the inputs and outputs in response to the user programmed instructions in memory, and it energizes or de-energizes outputs as result of the logical comparisons made through these instructions.

Spherical Coordinate System - A coordinate system, two of whose dimensions are angles, the third being a linear distance from the point of origin. These three coordinates specify a point on a sphere.

Teach Pendant - The control box which an operator uses to guide a robot through the motions of its tasks. The motions are recorded by the control memory for future playback.

Tool Center Point (TCP) - A given point at the tool level around which the robot is programmed for task performance.

Vision - A sensory capability involving the image of an object or scene.

Work Envelope (Working Envelope) (Robot Operating Envelope) - The set of points representing the maximum extent or reach of the robot hand or working tool in all directions.

Wrist - A set of rotary joints between the arm and end-effector which allow the end-effector to be oriented to the workpiece.

Yaw - Side to side motion at an axis.

3.0 SELECTION OF APPLICATIONS AND RANKING

3.1 Areas Chosen for Examination

Because the scope of this study encompassed the entire Distribution Directorate, which includes over 60 locations and facilities and associated support activities, an organized process for application selection was a necessity for efficient investigation. Because of time and manpower constraints, the number of areas to be examined was reduced. The decision to select certain areas for study was supported by the similarities among many of the operations such that complete examination of all of the facilities would be redundant.

Selection of the areas to be examined was based on historical activity level and manpower intensity. Specific data for these items was furnished by the Directorate liaison person and various data processing personnel. From this data, the total weekly/monthly man-hours, average weekly/monthly transactions, and transactions per man-hour were computed. Tables 2 and 3 illustrate these values. While all of the values were informative, "total transactions" was ultimately used as the basis for selecting facilities for detailed examinations. Unlike the "transactions per man-hour" values, the "total transactions" value reflects differences in varying levels of automation among the facilities. It also provides an indication of the economic potential based on idle and active time. Figure 11 charts each area with its respective total transactions for 1983.

The areas initially chosen for examination (and their respective facility number) were:

- WICS Warehouses (641)
- Shipping (376)
- Receiving (376)
- Air Freight (127)
- Serviceable Parts (385)
- Repairable Parts (380)
- Kits and Metals (301)
- Warehouse and Gun Room (368)

Table 2

TRANSACTIONS AND MAN HOURS BY FACILITY

BUILDING	TOTAL WEEKLY EMPLOYEES	TOTAL WEEKLY MAN HOURS	TOTAL TRANSACTIONS	AVE MONTHLY TRANSACTIONS	AVE. WEEKLY TRANSACTIONS	TRANSACTIONS PER MAN HOUR
59			46137	3844.75	887.25	
125	2	80		0	0	
127AIR FRT	177	7080	555204.8	46267.07	10677.02	1.508053
196	60	2400		0	0	
300	219	8760		0	0	
301	35	1400	67240	5603.333	1293.077	.9236264
309			5935	494.5833	114.1346	
310	187	7480	7545	628.75	145.0962	.0193979
327			24264	2022	466.6154	
350	73	2920	33	2.75	.6346154	.0002173
351	53	2120	43188	3599	830.5385	.3917634
357	3	120		0	0	
365	107	4280		0	0	
366	5	200	11917	993.0833	229.1731	1.145865
367	21	840	6624	552	127.3846	.1516484
368	37	1586	51312	4276	986.7692	.6221748
376RECEIVING	122	4880	772309	64359.08	14852.10	3.043462
376SHIPPING	73	2920	867333	72277.75	16679.48	5.712151
376PACKAGING	33	1320		0	0	
380	64	2560	209177	17431.42	4022.635	1.571342
385	65	2600	538626	44885.5	10358.19	3.983920
641	163	6520	1008594	84049.5	19396.04	2.974853
641PACKAGING	62	2480		0	0	
660			5965	497.0833	114.7115	
PB36	122	3780		0	0	
Total	1683	66326				

Note: Blank spaces indicate data not available

Table 3

ISSUES AND RECEIPTS BY FACILITY

LOCAL ISSUES FOR 1983

BUILDING	TOTAL	MONTHLY AVERAGE	RANK
59	24169	2014.08	6
301E	39050	3254.17	5
301W	248	20.67	15
309	836	69.67	12
310	1781	148.42	11
327	20645	1720.42	7
350	0	.00	17
351	4997	416.42	9
366	441	36.75	13
367	2097	174.75	10
368A-C	7125	593.75	8
368D,E	404	33.67	14
380	39311	3275.92	4
385	106800	8900.00	3
660	123	10.25	16
641	261410	21784.17	2
OTHER	309131	25760.92	1
TOTAL	818568		

OFF-BASE ISSUES FOR 1983

BUILDING	TOTAL	MONTHLY AVERAGE	RANK
59	10415	867.92	7
301E	8260	688.33	9
301W	1199	99.92	14
309	2244	187.00	12
310	3909	325.75	10
327	107	8.92	16
350	0	.00	17
351	14113	1176.08	5
366	8998	749.83	8
367	2950	245.83	11
368A-C	23949	1995.75	4
368D,E	1509	125.75	13
380	11133	927.75	6
385	292185	24348.75	2
660	491	40.92	15
641	392095	32674.58	1
OTHER	93776	7814.67	3
TOTAL	867333		

RECEIPTS FOR 1983

BUILDING	TOTAL	MONTHLY AVERAGE	RANK
59	11553	962.75	8
301E	16744	1395.33	6
301W	1739	144.92	14
309	2855	237.92	11
310	1855	154.58	13
327	3512	292.67	10
350	33	2.75	17
351	24078	2006.50	5
366	2478	206.50	12
367	1577	131.42	16
368A-C	16713	1392.75	7
368D,E	1612	134.33	15
380	158733	13227.75	2
385	139641	11636.75	3
660	5351	445.92	9
641	355089	29590.75	1
OTHER	28746	2395.50	4
TOTAL	772309		

BUILDING	FINAL TOTALS	FINAL RANK
59	46137	7
301E	64054	5
301W	3186	16
309	5935	14
310	7545	11
327	24264	9
350	33	17
351	43188	8
366	11917	10
367	6624	12
368A-C	47787	6
368D,E	3525	15
380	209177	4
385	538626	2
660	5965	13
641	1008594	1
OTHER	431653	3
TOTAL	2458210	

TOTAL TRANSACTIONS FOR 1983
PER BUILDING

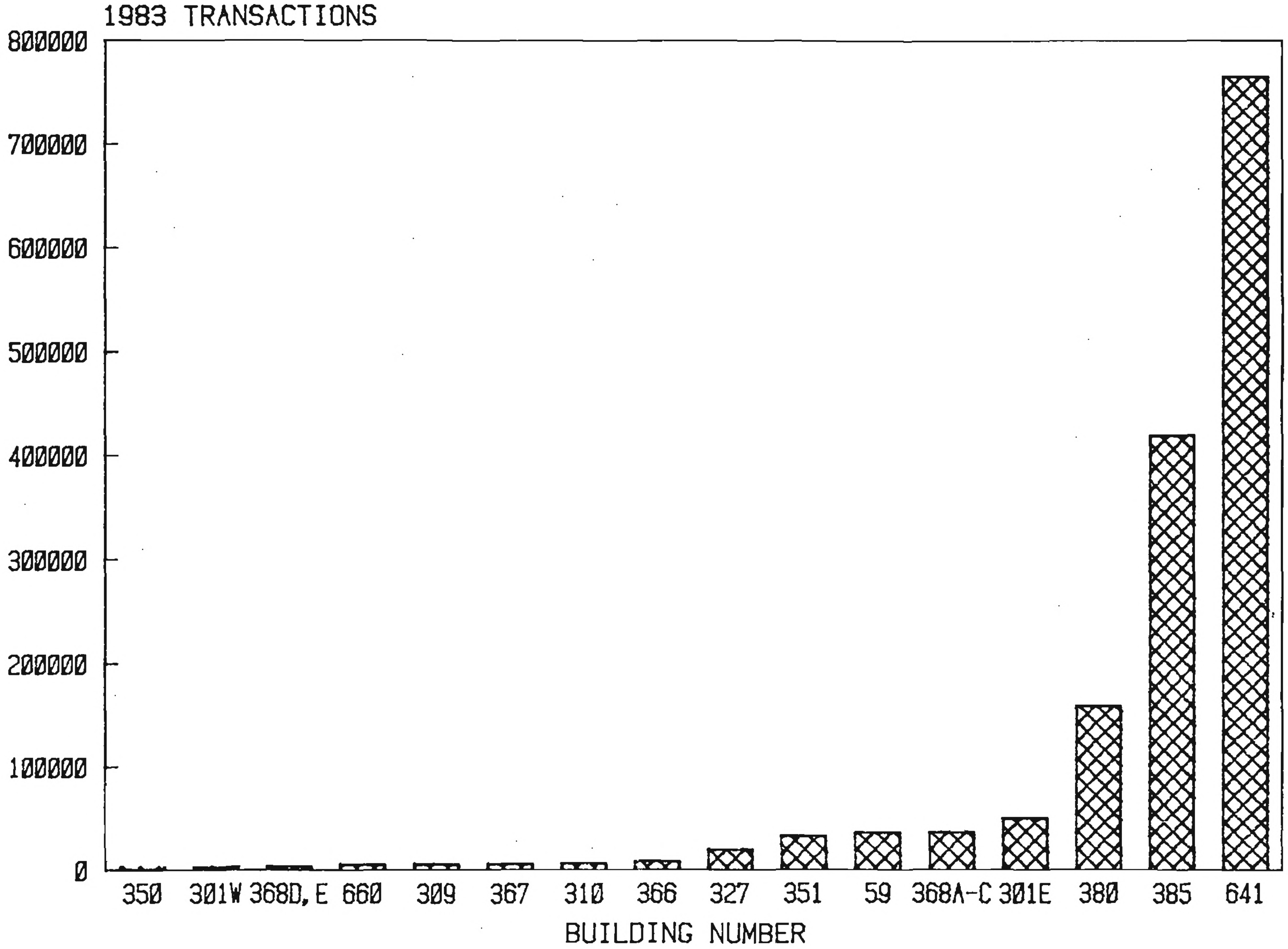


Figure 11

- B-52 Warehouse (59)
- Classified Warehouse (351)
- Hazardous Materials (327).

Throughout the examination period, occasional side excursions were made to other areas based upon input from the Directorate liaison person and as need arose. The feasibility study for gyro packaging was uncovered during one such excursion.

3.2 Task Evaluation

Each research team member was assigned to facilities from the initial list. The examinations by the team members utilized three basic tools: flow charts of operations, job analysis charts, and task assessments. This methodology starts at the macro level of the materials flow and continues to break down the operations to the person and task level. Evaluations of tasks appropriate for automation were rigorously scrutinized in themselves and in context of the overall operation of the facility.

First, the methodology required that a process flow chart be made to describe the movement of both materials and respective information throughout the facility. From this flow chart, each material handling operation was described. Figure 12 is a representative example of a process flow chart for the "on-line processing" operation in the shipping area (376).

Second, an analysis was made for each operation. This was accomplished by direct observation and by interviewing operators to determine job responsibilities, decisions, and actions.

The process for analyzing each operation for possible robotic implementation involves many elements and could lead to confused and biased decisions if the analysis is not properly organized. In order to simplify the process of analysis and also to support objective decision making, the analyst used a job analysis chart to place a numerical value on his observations to assist in the ranking of that operation for robotic feasibility.

Ensuring objectivity in the decision making process required the incorporation of several measures to reduce bias. These measures included:

FIGURE 12

ON-LINE PROCESSING
(Shipping - Building 376)

ENTER SHIPPING	
INITIAL SORTATION	Screen for Special Handling Items. Screen for Material Not Requiring Processing. Route Bulk On-Line Materials.
ON-KICKER OPERATION	Route Items to Proper Chute for Packing. Remove Items Not Having Processing Location.
ON-LINE PROCESSING PACKING	Verify Material with Document. Package Material. Enclose or Attach 3 Copies of 1348 Document. Attach Remaining Copies for Later Use. Send Package to Router. OR Verify All Material Designated for Consolidation Has Arrived. Package Material in One or More Large Containers. Establish a Lead Document or Split Documents. Send Package to Router.
ROUTER	Remove Document. Assign Transportation Mode to Document. Send Material to TAALS.

FIGURE 12

ON-LINE PROCESSING
(Shipping - Building 376)
(Concluded)

TAALS	Remove Document. Keypunch Card. Match Document. Read Card. Match Card. Weigh and Cube. Attach Label. Reweigh, If Necessary.
INSPECT	
SORT	Route to Air Freight or Appropriate Carrier.
CARRIER CONSOLIDATOR	Reweigh to Check TAALS Weight. Establish Shipping Cost. Segregate by Carrier. Consolidate Material in Portable Bins. Move Bins to Area Designated for Carrier.

- Assigning a defined set of responses to each criteria representing all acceptable possible responses.

- Assigning only numerical values of either 1 or 0 to each response rather than using a graduated scale. For example, the response which implies robotic feasibility receives one point while a response which implies robotic infeasibility receives zero points.

- Evaluating each criterion equally rather than a weighting their respective importance. Equal weighting prevents the possible elimination of a robotic capability, which is initially considered more important than other capabilities for assessing robotic feasibility.

After each operation had been assessed in terms of response to the chart criteria and respective valuation, the points were then summed for a total that represented the robotic feasibility rank. A high ranking indicated a high potential for feasible robotic implementation. Figure 13 shows a representative operation analysis chart used in the shipping facility.

Third, a Detailed Task Assessment form was completed for the high-ranking operations. This form provides a structure of analysis for a particular task based on robotic qualifications and requirements. The task assessment form is shown in Figure 14.

3.3 Ranking and Final Selection

After all operations and tasks assessments were conducted, each team member suggested potential robotics applications based on the most promising task assessments. The research team then collectively held several evaluation sessions at which time all blatently mechanical and economically impractical applications were eliminated. All other possibilities were discussed and evaluated in a "pro/con" manner as described in the example in Figure 15. These evaluations included criteria of technical viability, ease of installation, cost effectiveness, and transferability to other operations.

A list of the ten most promising applications for robotic automation resulted from these discussions. The list, including each application's major

Figure 13

Analysis Chart

JOB IDENTIFICATION	UTILIZES CHARTS/STANDARDS	REQUIRES GUAGING	REPETITIVE	VARIES SIGNIFICANTLY	CONTINUOUS WORK	DANGEROUS		ROBOTIC FEASIBILITY RANK
Initial On-Line Sorter	Y	V	N	Y	N	T/K		1/6
On-Line Kicker Operator	N	N	N	N	N	T		4/6
Bulk On-Line Kicker Operator	N	V/H	N	N	N	T		3/6
Single-Shipment Packer	Y	V/H	N	Y	Y	N		1/6
Consolidation Packer	Y	V/H	N	Y	Y	K		2/6
Marking Router	Y	N	N	N	Y	N		2/6
TAALS Keypunch Operator	N	N	N	N	Y	N		4/6
TAALS CRT Operator	N	N	N	N	Y	N		4/6
TAALS Labeler	N	N	N	N	Y	N		4/6
TAALS Inspector	Y	V/H	N	Y	Y	N		1/6
Mode Kicker Operator	Y	N	N	Y	N	N		1/6
Carrier Consolidator	Y	N	N	Y	N	N		1/6
Off-Line Packing	Y	V/H	N	Y	Y	K		2/6
Forklift Operator	N	V/H	N	Y	Y	K/H		3/6
Crate Shop Operator	Y	V	N	Y	Y	K/T/H		2/6

KEY: V = Vision, H = Hearing, T = Touch, K = Kinaesthetic, Y = Yes, N = No

FIGURE 13
(Continued)

POINT SYSTEM FOR ROBOTICS FEASIBILITY RANK

Column Terms	Response	Points
Utilizes Charts/Standards	Yes No	0 1
Requires Guaging	Yes No	0 1
Repetitive	Yes No	1 0
Varies Significantly	Yes No	0 1
Continuous Work	Yes No	1 0
Dangerous	Yes No	1 0

Total Points Available = 6.

FIGURE 13
(Concluded)

INTERPRETATION OF CHART TERMS

Column Terms

UTILIZES CHARTS/STANDARDS: Refers to the procedure of taking data and using given standards to formulate a result. Such a procedure qualifies for the ease in use of a specifically programmed database package if computer time were available.

REQUIRES GUAGING: Refers to the procedure of estimating data and using judgment to formulate a result. Such a procedure could not utilize the services of a computerized database software package.

REPETITIVE: Describes the frequency of a recurring motion, action, or task. A "yes" response would indicate that each item is processed identically using the same information, containerization, labeling, etc.

VARIES SIGNIFICANTLY: Describes those operations whose motions and actions vary with each item; that is, each item requires decision making for processing according to priority, classification, and size.

CONTINUOUS WORK: As opposed to batch-type work, this refers to the continual work activity due to material flow, as well as time involvement of the operation. This term, of course, excludes lunch and break time.

DANGEROUS: Describes tasks, as well as the immediate environment of the operation, which could possibly have hazardous affects on the operator.

Key Terms

VISION: Refers to the sight ability only, not literate abilities, such as using on'e sight to read the 1348 document.

HEARING: Refers to the hearing ability.

TOUCH: Refers to the tactile sense, especially the hands and fingers.

KINAESTHETIC: Refers to the muscles, tendons, and ligaments of the body. Danger to these areas could result in muscle strain, pulled muscles, torn tendons or ligaments, or pinched nerves caused by muscle tension.

YES: A "yes" response indicates that the description from the column heading using these preceding interpretations properly describes the operation.

NO: Likewise, a "no" response indicates that the description from the column heading does not describe the operation according to the interpretation of these terms.

DETAILED ASSESSMENT CRITERIA

Job Title: ______________________________

	Comments

1. Hazard:

Human		Robot	
_____	Hand	_____	Manipulator
_____	Eye	_____	Hand
_____	Ear	_____	Controller
_____	Nose	_____	Temp
_____	Back	_____	Corrosive
_____	Temp	_____	Other

2. Operator Tasks:

_____ Boring
_____ Repetitive
_____ Tiring
_____ Stressful
_____ Creative
_____ Decision Required
_____ Interesting

3. Inspection:

_____ Eye
_____ Touch
_____ Gauge
_____ Use Device
_____ Use Machine
_____ Cannot Automate
_____ N/A

4. Quality:

_____ Operator Controls
_____ Operator Not A Factor
_____ Can Handle Upstream
_____ Can Handle Downstream
_____ Robot Can Handle
_____ Periphery Can Handle

5. Part Presentation:

_____ Unoriented
_____ Need Extensive Orientation
_____ Hard to Pick Up
_____ Easy to Pick Up
_____ Can Automate
_____ Cannot Automate

	Comments
6. Part Weight (lbs):	
____ 0-1 ____ 50-100	
____ 1-5 ____ 100-250	
____ 5-10 ____ 250-500	
____ 10-25 ____ 500 +	
____ 25-50	
7. Product Variation:	
____ Little ____ Great Deal	
____ Some ____ N/A	
8. Product Runs:	
____ Too Short	
____ Too Long	
____ Right Length	
____ Random Length	
9. Frequency of Changeover:	
____ ½ hour ____ 1 week	
____ 1 hour ____ 1 month	
____ 4 hours ____ 6 months	
____ 8 hours ____ N/A	
10. Process Variability:	
____ Extremely Variable	
____ Moderately Variable	
____ Slightly Variable	
____ Non-Variable	
11. Existing Process Equipment:	
____ Can Be Automated	
____ Modifications Easy	
____ Modifications Difficult	
12. Floor Space:	
____ Readily Available	
____ Not Available	
13. Cycle Time:	
____ Too Fast ____ Good	
____ Too Slow ____ N/A	

FIGURE 15

PRO/CON ASSESSMENT OF
GYRO PACKING AND DEPACKING AREA

Process and Characteristics	
• Depack Gyros for Repair with Robot • Pack Repaired Gyros for Storage or Shipment • Gyros Packed in Foam Lined Boxes, Vacuum Sealed, then Packed in Larger Foam Lined Boxes • Relatively Small Number of Different Items Handled • Three Basic Packing Methods Employed • Repaired Gyros can be Provided to Robotic Packing System in Precise Location and Orientation	
PROS	CONS
- Limited Variety of Item Types - Preorientation and Identification of Items Possible - Task Well Within Robot Capabilities - May be Performed with Off-the-Shelf Hardware	- Small Operation - High Cost Items

location of occurrence, is presented in Figure 16.

The information from the "pro/con" evaluations and the list of ten applications were the subject of a meeting between the research team and Mr. Tommy Haskins, Distribution Directorate management staff, and Mr. Robert Brown, the designated technical liaison for the project. The advantages and disadvantages of each application were presented in the context of the immediate area which would be affected, as well as the impact on overall distribution operations and future utilization of robot systems.

A brief summary of each of the proposed applications follows and includes considerations posed by Distribution Directorate personnel and the collective conclusions which were reached.

Sorting - Sorting is a manual work element which occurs throughout the distribution operations. The automation of the sorting process at the Air Freight Terminal was presented as an opportunity which could provide important experience in a well structured environment. However, it was not anticipated to be a cost effective installation considering the technical development required and the low level of manual labor displaced. The automation of sorting at air freight was chosen as one of the three opportunities which would be investigated in greater detail in consideration of future potential for robots in distribution tasks.

Weigh and Cube, and Labeling - The TAALS (Transporating Automatic Addressing and Labelling System) area in shipping suffers from extensive manual document handling requirements which retard the material flow and processing time. Automation of this area to reduce or eliminate the manual handling of documents could result in increased throughput, capacity, reduced errors, and lower manpower requirements. This opportunity was also chosen for further investigation on the basis of projected cost effectiveness and moderate development effort. The two applications, weigh and cube, and labeling, were combined into a single TAALS automation concept.

Depalletize - This task occurs primarily in the receiving areas and at the air freight terminal. Automation of the depalletizing process was projected to be extremely complex, requiring extensive development in software and sensors. Depalletizing requires the removal of pallet securing straps and wrappings, the identification of individual items, the gripping of those

FIGURE 16

POTENTIAL APPLICATIONS FOR ROBOTIC AUTOMATION

	Location					
Task	Shipping	Receiving	Air Freight	WICS	385	Others
Sorting	*	*	*	*	*	*
Weigh & Cube	*					
Labeling	*					
Depalletize		*	*			
Consolidation	*					
Palletize	*		*			
Break Consolidations		*				
Packaging		*		*		*
Box Making						*
Laser Etching						*

items, and their removal from the pallet. The wide size and shape variability of the palletized items received at shipping and air freight led to the elimination of this task for consideration of further feasibility assessment.

Consolidation - In shipping, consolidation of small items into larger shipments is a labor intensive task, that could lend itself to automation. The task, while viable for a robot, would require the use of complex vision sensors and software are the development of novel hard automation concepts which are unproven and present a high developmental risk. These considerations, as well as the limited scope of applicability, precipitated the dismissal of this application from further feasibility assessment.

Palletize - This task occurs in shipping and in the air freight terminal. It would involve a robotic system of a complexity equal to or greater than that proposed for consolidation, and would require extensive developmental risk. Considering that the task was isolated, with minimal applicability in other Distribution Directorate facilities, this application was ranked below those considered for further assessment.

Packaging - Packaging tasks occur in several facilities within the Distribution Directorate. Robotic packaging tasks were seen to present opportunities which would have widespread applicability. Packaging opportunities were investigated in shipping, receiving, and gyro pack and depack. The environment in the gyro pack area was determined to be the most conducive to robotic automation because of the limited variability of items which are handled and the clearly defined packaging procedures. The automation of the gyro packaging process became the third area for further examination.

Box Making - The box factory currently fabricates small lots of custom fiberboard boxes and wooden crates. Manual setup of the fiberboard cutting machinery represents a high percentage of the time required to make a batch of boxes. A system for the automated setup of a fiberboard box making unit was proposed. The opportunity was ranked below those considered for further assessmnet on the basis of its limited expected savings and its isolated nature.

Laser Etching - A small experimental program is being undertaken to etch LOGMARS bar codes on weapons. There is some danger to the operator while loading weapons into the etching unit, necessitating cumbersome optical shielding. The opening and securing of this shielding limits the speed at which weapons can be processed. Robotic automation could significantly improve throughput rates since the robot could work within the shielded area. The limited applicability of this opportunity ranked it below those considered for further examination.

The applications chosen for further feasibility assessment were then prioritized by mutual agreement between the Georgia Tech team and the Distribution Directorate management as shown below. Preliminary feasibility analyses for these applications are presented in this report in the following order:

1. Gyro Packaging
2. TAALS Automation
3. Sortation in the Air Freight Terminal.

4.0 FEASIBILITY STUDIES

4.1 Methodology

There are three general areas to be addressed in the feasibility analysis of a robotics system. These include the system design, the economic assessment, and the impacts of the system on peripheral and supporting operations. Table 4 shows the significant items in each of these categories.

4.1.1 System Design

Our approach to system design treats the functional requirements of a task as the work elements of the task rather than as an exact replication of the actions of a human worker. This approach allows for restructuring of task elements and sequences. These modifications can lead to efficiency improvements in themselves and when they are matched to the capabilities of the robotic system. The marrying of the appropriate technologies to the functional requirements of the task (and the allowance for restructuring of work elements) tends to be an iterative process leading to system design alternatives.

In the automation of a system, the goal is to be able to perform each task with the agent which is best suited to that level of complexity of manipulation. We considered the performance of each work element to be satisfied by robot automation, "hard" automation, or human operation. It is important to emphasize here that the human operator represents the highest level of manipulative capability. Those motion and cognitive skills, so as not to be wasted on tasks which do not require those skills, were reserved for more challenging tasks. Simple repetitive tasks were achieved with hard automation, if possible. The repetitive tasks which required a level of flexibility, complex motions, or "sensory" feedback were considered appropriate in the design to be performed by a robot. Those tasks which were too variable for a robot, or which required the integration of information from a number of senses, intuition decision making, or a complexity of motion beyond the capabilities of a robot were approached in the design to be performed by

TABLE 4
FEASIBILITY ANALYSIS METHODOLOGY

Design

- Definition of functional requirements
- Characterization of material being handled
- Proposed system configurations

Financial

- Production throughput
- Economic analysis - life cycle costs/benefits
    - System capital cost
    - System installation costs
    - System operating costs
    - Direct and indirect savings
    - Net present value and simple payback

Impact Assessment

- Impact of the system on:
    - Distribution operations
        - Material flows
        - Vulnerability
        - Mission capability
        - Computer systems
    - Maintenance
        - Hardware
        - Labor
    - Labor training
        - Programmers
        - Operators
    - Labor relations
        - Union acceptance
        - Inclusion of personnel in planning
        - Employee morale
    - Quality
        - Damage reduction
        - Materials Usage
        - Reduction in Rework
        - Reduction in Inspection

a human operator.

The characterization of materials to be handled was an important element in establishing the functional requirements in this highly variable environment. To achieve this characterization, data was collected on the key physical attributes of the materials under study. A statistical analysis performed on the data predicted the boundaries and mean values of these features.

The process of selecting a viable system configuration derives from experience with robotic systems capabilities and the functional requirements of the task as previously described. The process of matching applicable technologies to discrete task functions would usually lead to the proposition of several alternative system concepts. Those alternatives were then, in turn, evaluated as an operating system with particular attention paid to overall cost, ease of installation, and risk assessment. Ultimately, one system emerged as the most viable candidate for the application at hand.

4.1.2 Financial Analysis

The cost/benefit analysis used in the feasibility studies is based on a 10-year life-cycle economic analysis as suggested by the Distribution Directorate management. The production throughput for the proposed system establishes the direct labor savings and estimates for indirect savings in quality, inspection, and materials. Capital costs are derived from vendors' budgetary quotations and from engineering estimates for systems integration and installation costs. Operating costs are based on historical experience with robotics systems in regard to power consumption, maintenance requirements, training, and start-up.

4.1.3 Impact Assessment

The final considerations for the installation are judgmental estimates, but are, nonetheless, important to a thorough evaluation of the system. Operational impact includes improvements to material flows as a result of restructuring of the task environment or increased order in the process, as required for the robotics system.

The effect of the installation on overall mission capability as related to surge capacity or service improvement, as well as operation under mobilization conditions, are important items for the Distribution Directorate. Vulnerability of the system to damage from misuse, inexperience, or sabotage should also be considered.

Interactions with existing information systems are assessed to consider the load placed upon those systems and/or the need for expanded capacity. System failures are also considered in this context.

In the area of support requirements, the impacts of the system on maintenance include the requirements for hardware inventory and skilled maintenance labor. Training programs are necessary for maintenance, programming, and operating skills.

Labor relations impacts include acceptance by the labor force and union involvement, as well as morale issues stemming from job security concerns.

Finally, the quality impacts of the system are considered in regard to damage to the system, as well as to items being handled, improvements in the consistent usage of materials, and reductions in inspection.

4.2 Feasibility Study for Gyro Packing

4.2.1 Gyro Pack and Depack Operations

The gyro pack and depack area serves the gyro repair shop. Both facilities are located in building 159. Repaired gyros are packed into shipping or storage containers by personnel who also are responsible for unpacking gyros which are received for repair. Forty-five different gyro types are handled in the pack and depack area. Many of the gyros have similar exterior dimensions. Because of this, only 23 different packing requirements (called TPOs: Transportation Packaging Orders) are needed to pack all of the gyro types. A TPO consists of paper wrapping, vacuum sealing, desicants, various sized boxes, and foam liner inserts.

All pack and depack activity is performed manually at the present time. The automation of either the packing or depacking tasks would allow for changes in the order of work elements as performed by the human personnel. The quality of packaging is the important measure of the success in the automation of the task. The use of a robot also opens up the possibility of using packaging methods which are environmentally objectionable to human workers, such as "foam-in-place." Consideration of alternate packing methods which might be suitable for use by robots will be covered in the impact assessment section of this study.

The following paragraphs outline the basic gyro depacking and packing tasks as they are presently performed:

A. Gyro Depack

Gyros are received in large fiberboard boxes. Generally more than one gyro is packed in each box. The gyros are packed in plastic foam for protection in transit.

When a box is received, it is opened manually and the contents are removed. The gyros are separated from the packing material, placed in carts, and taken to the gyro repair shop.

B. Gyro Pack

Repaired gyros are transported from the gyro repair shop to the gyro pack area on carts. Small gyros are placed in foam-padded individual sections of fiberboard boxes. Large gyros are placed directly on the shelf of the cart. In all cases, a physical separation is provided between the gyros, and they are arranged in a regular pattern. They are never stacked on top of each other or randomly scattered about the shelf of the cart.

The packing personnel selects a gyro and identifies it by the tag which is attached to it in the repair shop. The gyro stock number determines which TPO is required for packaging. Twenty-three different TPOs are used to pack the 45 different gyros handled in this area. Many of the TPOs are interchangeable, so that a given gyro may be packed in any of several different TPOs. A total of 18,890 gyros were packed in the period from May 1983 to May 1984.

The packing of a gyro is generally performed according to the following procedure. The gyro is loosely wrapped in brown paper which is then taped in place. The gyro is then placed in the inner box of the TPO. This box generally contains a block of foam which has either a rectangular hole or a star-shaped hole (star pack). The gyro is placed into this hole in an orientation which is dependent on the gyro being packed. The top flaps of the inner box are then folded over and taped.

Almost all gyros are vacuum packed. Vacuum packing is accomplished by placing the inner box in an aluminized heat-sealable bag. The open edge of the bag is then heat sealed, leaving only a small hole at one corner unsealed. A small tube is slipped into this hole to evacuate the bag. The vacuum source is a compressed-air driven aspirator unit. Once the bag is evacuated, the evacuating tube is removed and that corner is heat sealed.

The vacuum sealed inner box is then placed into the foam lined outer box, which is generally in the form of a "slide pack." The top part of the box contains a foam insert which fits into the rectangular hole in the foam in the base of the box. The inner box is completely surrounded by foam once the outer box is closed. The outer box is sealed with tape, and taken to a holding area for transportation.

4.2.2 Gyro Pack Functional Requirements

The robotics application in the gyro pack and depack area is the automation of the gyro packaging task. This task has been described in the previous section. A necessary step in the specification and evaluation of an automated system is the definition of the functional work elements which that automated system must accomplish. Each functional element may be performed by hard automation equipment, by a robot, or by a human operator. By examining each functional requirement individually and in the context of the other functional requirements which must be accomplished, the most appropriate level of manipulative capability can be chosen for the task. The selection of the manipulating agent--hard automation, robot, or human--may then be accomplished. The functional requirements to perform this activity are listed below. Each item represents a separate element which may be performed by a specialized piece of automated equipment, or by a general purpose device such as a robot.

- Locate gyro
- Identify gyro
- Obtain TPO
- Prepare TPO
- Grasp gyro
- Verify gyro type
- Wrap gyro
- Box gyro
- Vacuum seal gyro
- Pack inner box in TPO
- Seal and label TPO
- Move TPO to shipping area.

Following, is a description of the general requirements necessary to satisfy each item.

Functional Requirement: Locate Gyro

Before any agent can pack a gyro it must first have knowledge of the location of the gyro. Locating the gyro could require a complex vision system capable of determining the position and orientation of the gyro in a cluttered visual field, or it could require only simple fixturing.

Functional Requirement: Identify Gyro

Each gyro is identified by a stock number which is listed on a tag attached to the gyro, as well as engraved on the gyro. Identification may be accomplished through the acquisition of this stock number, or through the recognition of physical characteristics.

Functional Requirement: Obtain TPO

Before a gyro can be packed, the TPO in which it will be packed must be available. At least one TPO type exists to pack each gyro. The TPO number can be identified once the gyro stock number is known. The identified TPO must then be acquired, prepared, and presented to the packaging agent.

Functional Requirement: Prepare TPO

All TPOs must be prepared in some manner before they can be used in the packaging process. This preparation may be as simple as opening the flaps of a box, or as involved as partially or completely removing packing material and stabilizing inserts. Once prepared, the TPO can be presented to the packaging operation.

Functional Requirement: Grasp Gyro

Gyros are delivered from the gyro repair shop in partitioned boxes or on the shelves of a cart. The gyro must be grasped in order to perform the packaging operations on it. Grasping a gyro requires careful monitoring of the pressure applied and the location of the points of contact to insure that no damage occurs. Slippage of the gyro in the grasping device must also be detectable to anticipate the loss of grip and potential damage which may result.

Functional Requirement: Wrap Gyro

Gyros are wrapped in paper for protection from other packing material and from contact with a dessicant, if present. This wrapping may be accomplished using techniques other than those presently used. Wrapping the gyro in paper is functionally equivalent to placing it in a paper bag and sealing the bag.

Functional Requirement: Box Gyro

The wrapped gyro must be placed in the inner box of the TPO. In many cases, this is a simple matter of inserting the gyro into a specially shaped hole in the foam packing material in the inner TPO. Other gyros require a more complex procedure, which may include attaching the gyro to a wooden support before placing it in the inner TPO. The inner box must then be closed and sealed.

Functional Requirement: Vacuum Seal Boxed Gyro

Vacuum sealing is accomplished by placing the boxed gyro into an aluminized vacuum seal bag, partially sealing the open edge of the bag, applying the vacuum, and finishing the sealing of the open edge. Provision must be made to prevent air pockets from forming during the process.

Functional Requirement: Pack Inner Box in TPO

The vacuum sealed inner box is generally inserted into a suitably sized cubical hole in the foam liner of the slide pack outer box of the TPO. The agent handling this activity must be able to align the inner box with the hole and be able to cope with the binding of the box against the foam packing material as the inner box is inserted.

Functional Requirement: Seal and Label TPO

The outer box of a TPO is generally a slide pack. Sealing the TPO involves placing the top of the slide pack on the TPO and securing it with tape. The box must be then labeled to show its contents.

Functional Requirement: Move TPO to Holding Area

The external dimensions of the packed gyros vary over a considerable range. The handling system must be able to accommodate the variations in size and weight.

Statistical data on gyro types and physical properties are presented in Appendix E of this report.

4.2.3 Gyro Packaging Proposed Systems

Two concepts for the automation of the gyro pack area are proposed. The first concept could be implemented in the near term, combining a robotic system with human operators and hard automation. The second concept is for total automation of the gyro packaging task in the future.

Near-Term, Automated Gyro Pack Proposed System

The present gyro pack and depack operation employs five full time workers and one half-time supervisor. The near term system would automate packaging from the point of gyro acquisition through vacuum sealing. This should free up three of the workers for more challenging work in other operations. The remaining two workers would continue to depack gyros and also to be involved in providing materials to the robot work cell, and completing the packing, sealing, and labeling of the packed gyros. These workers would also perform part of the packaging task for uncommon gyros which have unusual packaging procedures, such as bolting the gyro onto a wooden support prior to placement in the inner box of the TPO. The supervisor could be trained in maintenance and programming of the robot system, and would remain at a half-time level of involvement.

The automated gyro packaging system, shown in Figures 17, 18, and 19, is designed around a spherical coordinate robot. The robot serves several pieces of hard automation which perform portions of the packaging task. The partially packaged gyro is then delivered to the human operator, who completes the packaging and labeling process. The following paragraphs describe the system components and their satisfaction of the associated functional requirements.

The gyros are received from the gyro repair shop on the shelves of a cart or in partitioned cardboard boxes. The operator places the tray or box of gyros at the acquisition station. Preorienting the tray or box at the

Figure 17

GYRO PACKAGING ROBOT

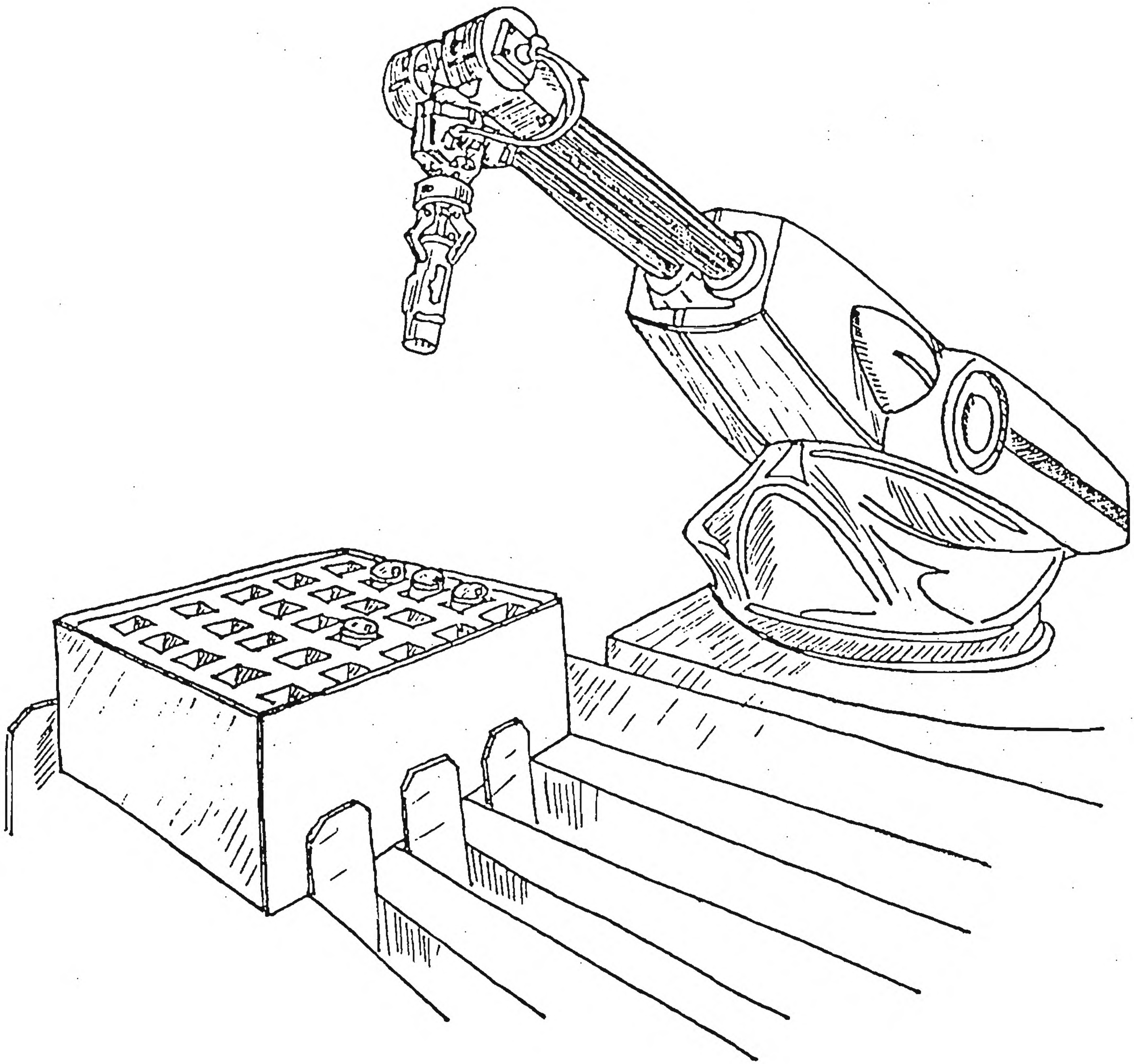


Figure 18

AUTOMATION OF GYRO PACK

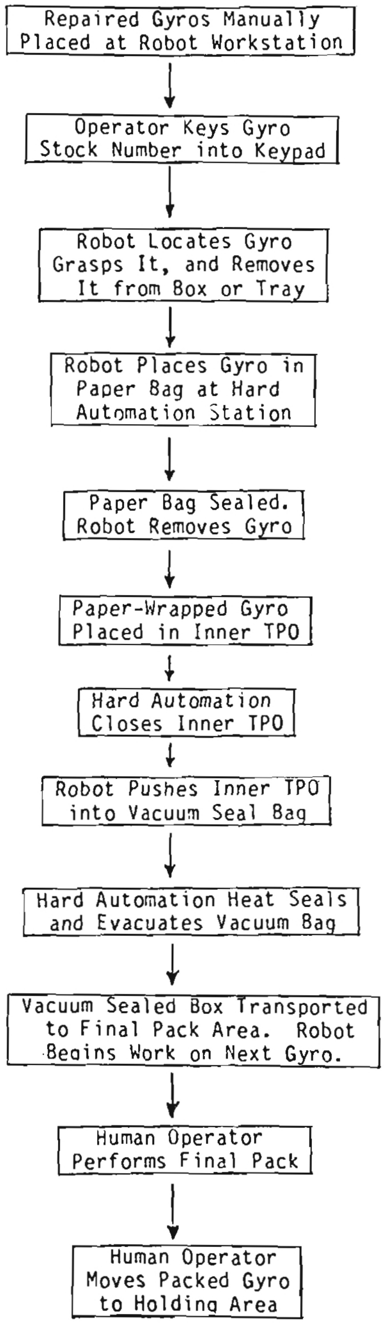
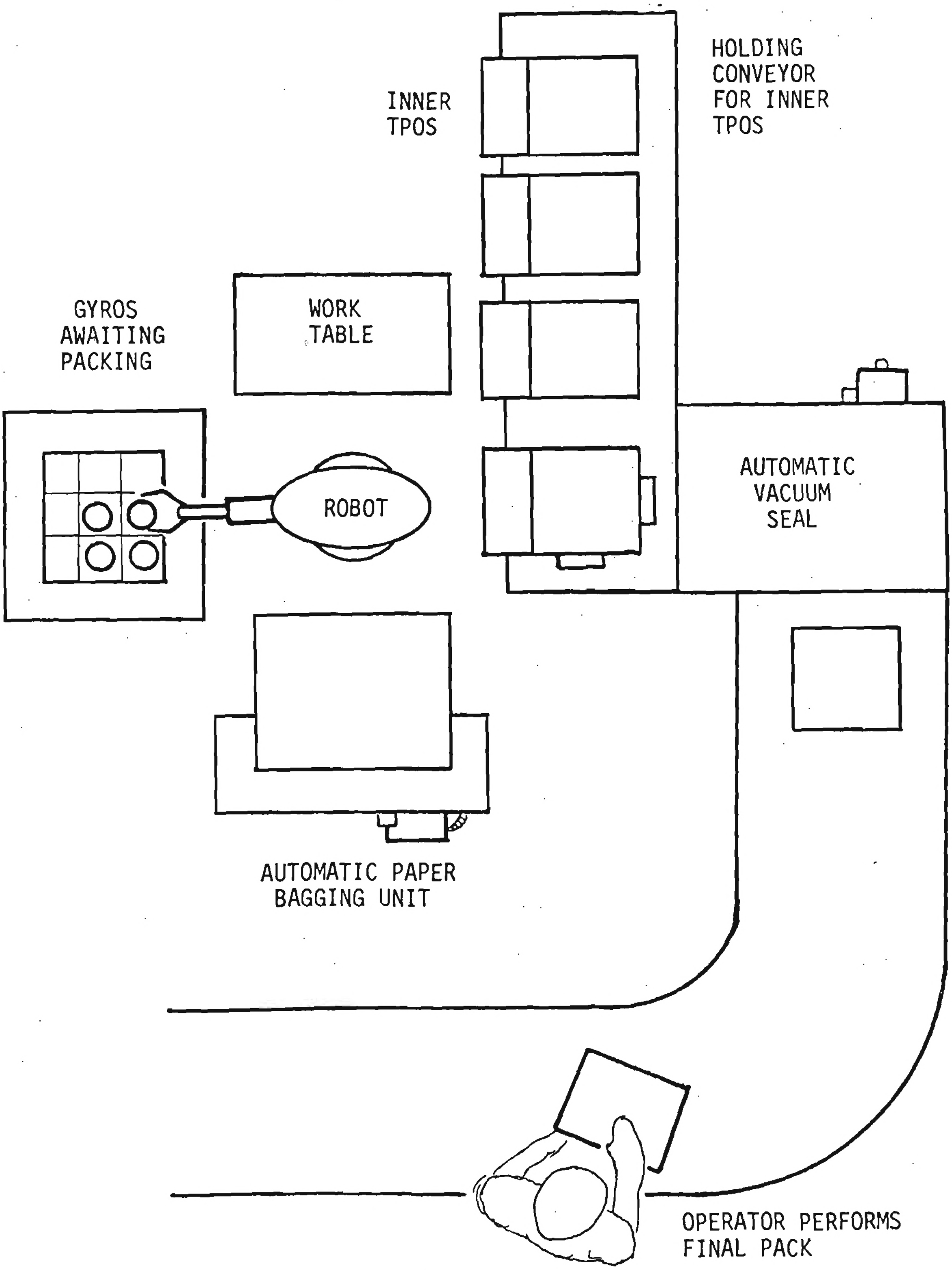


Figure 19

AUTOMATION OF GYRO PACK

PHYSICAL LAYOUT



acquisition station satisfies the functional requirement of locating the gyros for the robot. A simple locating fixture might be utilized.

After loading the gyro acquisition station, the operator keys the stock number for that set of gyros into a keypad. This informs the robot control system of the identity of the gyros, satisfying that functional step.

The computer system responds to the data input by displaying the TPO number which will be needed in the packaging of those gyros. The operator selects the requisite number of specified TPOs from the storage area. The TPOs are prepared by the operator and their components are placed on the queuing conveyors which feed the various stations of the work cell. This satisfies the functional aspects of obtaining and preparing the TPO.

While the operator is obtaining and preparing TPOs, the robot is manipulating gyros. Grasping of gyros requires several sensory capabilities. The presence of a gyro is detected by a simple contact sensor located at the tip of the robot gripper. As the robot slowly lowers its gripper over a possible gyro location, the contact sensor will register the presence of a gyro. The contact sensor is constructed with a whisker-like extension which allows the control computer to register contact with a gyro without exerting a significant force which could damage it. Once located, the robot opens its gripper to the size required for the gyro, moves into position, and grasps the gyro, thereby satisfying that functional requirement.

The gripper must incorporate tactile or pressure sensors. It is crucial that the gripper apply only as much pressure to the gyro as is necessary to safely manipulate it. The tactile sensors can also detect slippage. If a gyro begins to slip, the robot controller directs the robot to take corrective actions as the robot could easily cause damage to a gyro which had slipped out of position in its gripper.

The robot delivers the gyro to a hard automation paper bagging unit. After placing the gyro into a bag held by the bagging device, the robot then releases its grasp on the gyro and removes its gripper from the bag. The bagging device closes and seals the bag, satisfying that functional capability. The hard automation device operates in a manner similar to devices which are used to package food in paper sacks. The paper bagged gyro is then regrasped by the robot gripper and moved to the boxing station. A special or dual function gripper may be required for this element to preclude tearing the paper bag.

The boxing station consists of a hard automation device which holds the inner TPO box and packing inserts previously supplied by the operator. The robot places the wrapped gyro into the inner box, puts in place any foam or rigid inserts needed and withdraws. The hard automation device then closes and seals the box flaps and releases the box, completing the boxing functional step.

Immediately behind the boxing station is the vacuum sealing station. This hard automation device prepares for the vacuum sealing of the inner TPO box by grasping a vacuum seal bag, inflating it with air and a static charge, and holding it open in a vacuum frame. This activity is performed while the gyro is being boxed. The robot pushes the boxed gyro into the bag, withdraws, and returns to the acquisition area. The hard automation vacuum sealing unit then streches the open edge of the bag between two tubes, and seals the edge between them. A vacuum is then applied through the tubes. Once the required vacuum has been reached in the bag, the tubes are withdrawn and the remainder of the bag's edge is sealed. This process is very similar to that used to package freeze dried food in foil lined plastic pouches.

Once the vacuum sealing is complete, the box is released for final packing. The operator places the inner TPO box in the foam lined outer box, then closes, seals, and labels the outer box. The packaged gyro is then placed in the appropriate holding area for transportation. The operator is also responsible for keeping the hard automation devices supplied with paper bags and vacuum seal bags. Sensors in the system will provide alerts when supplies are needed.

4.2.4 Economic Analysis

The preliminary specifications for the equipment in this system are presented in Tables 5 and 6 on the following pages. Cost estimates were derived from vender quotations, engineering estimates, and documented historical experience with robot systems. A ten-year, life-cycle economic anlaysis was performed as recommended by Distribution Directorate management. Currently accepted inflation rates for operating costs and labor savings (5% and 8%, respectively) were incorporated in the annual cash flows. A cash flow discount rate of 8% was used to reflect the current Federal cost of capital. This discount rate did not materially affect the outcome of the analysis over a range of 0% to 15%. No tax effects were utilized in this analysis as this would be a federally funded project, if undertaken.

The specifications for the robot and associated equipment were based on physical characteristics of the gyros and packaging requirements. The raw data used in the analysis appears in Appendix E of this report.

Budgetary quotations for the robot, fixed automation units such as the paper bagging and vacuum sealing equipment, and peripheral items were solicited from vendors. Costs used were upward rounded averages for conservatism and contingencies.

Installation costs are subjective engineering estimates based on experience with the equipment, installation, and advanced automation start-up. Published guidelines for robot installations suggest that a complete turnkey installation will cost two to three times the cost of the robot. Our estimates fall in the high end of this range.

Operating costs were also estimated based on published experience with these systems. Maintenance costs for a complete system usually average 10% of the cost of the robot. Utilities costs are usually negligible and training costs can vary widely depending on the number of operators and their associated skill levels.

The basis for direct labor savings in the gyro packaging task is the automation of 60% of the manual touch labor presently utilized. As was mentioned earlier, there are five workers in the pack and depack area, which is normally in operation one shift per day, five days per week. By direct observation, the time for one worker to manually package one gyro was approximately 12 to 19 minutes. Based on the current throughput of approximately 18,000 gyros per year, this task accounts for roughly 5,000 direct touch labor hours per year or the equivalent of three workers per shift.

It was also noted that the separation and restructuring of the pack and depack area would provide a more orderly and regulated flow of materials and work elements, allowing for improvements in efficiency for the depack tasks.

It was our opinion that the depack tasks and the human interactions with the proposed robot system could be easily accomplished with the remaining two workers. It is possible that further reductions in direct labor or the inclusion of additional tasks would result from the restructuring, therefore, a small productivity improvement of 5% was subjectively estimated and included in the annual savings.

TABLE 5

GYRO PACK ECONOMIC ANALYSIS

A. Equipment Specification and Capital Costs

Robot and Control System:	$ 80,000
Spherical Coordinate Robot	
Maximum Payload: 100 lbs.	
Arm Extension: 12 in. or more	
Programmable Robot Controller (point-to-point)	
Robot Gripper:	$ 18,000
Three Finger Configuration	
Open to 16 in. Diameter	
Payload: 15 lbs.	
"Whisker" Type Contact Sensor	
Grey Scale Tactile Pads on Fingers	
Conformable Gripping Surfaces	
Paper Bagging Unit:	$ 5,000
Automatic Bag Feed	
Automatic Bag Seal	
Handle Bags to 18 in. Wide	
Inner TPO Box Closing and Sealing Unit:	$ 8,000
Accept Boxes 8 to 18 in. sq.	
Fold Flaps and Seal	
Vacuum Sealing Unit:	$ 6,000
Automatic Heat Seal and Evacuation	
Box Size: 1 cu. ft.	
Bag Size: 24 in. Open Edge	
Short Roller Conveyors:	$ 2,000
24 in. Wide	
TOTAL EQUIPMENT COST:	$119,000

TABLE 5

GYRO PACK ECONOMIC ANALYSIS
(Continued)

B. Installation Costs

Facilities Preparation: Floor Rework Power and Utilities Labor	$ 15,000
Engineering and Software:	$ 25,000
Equipment Installation:	$ 20,000
Systems Integration:	$ 10,000
Test and Debug:	$ 10,000
Training Program Set Up (1st year): Operator Maintenance Programmer	$ 10,000
Spare Parts Inventory:	$ 5,000
TOTAL INSTALLATION COSTS:	$ 95,000

C. Operating Costs (Annual)

Utilities:	$ 500
Maintenance:	$ 8,000
Training:	$ 2,000
Programming:	$ 2,000
TOTAL ANNUAL OPERATING COSTS:	$ 12,500

TABLE 5

GYRO PACK ECONOMIC ANALYSIS
(Concluded)

D. Annual Savings

Direct Labor: 3-WG6 @ $11.00/hr (benefits loaded rate) x 2,000 hours/yr	$ 66,000
Productivity Improvement @ 5%	$ 3,300
Materials Reduction	$ 600
Damage Reduction (Gyro Repairs)	$ 1,000
TOTAL ANNUAL SAVINGS	$ 70,900

Table 6

Gyro Pack

Ten Year Life Cycle Economic Analysis

year	capital	operating cost	savings	depre-ciation	tax	accumulated savings	net present value
0	$214,000					($214,000)	($214,000)
1		$12,500	$70,900	n/a	n/a	($155,600)	($159,926)
2		$13,125	$76,572	n/a	n/a	($92,153)	($105,530)
3		$13,781	$82,698	n/a	n/a	($23,236)	($50,822)
4		$14,470	$89,314	n/a	n/a	$51,607	$4,190
5		$15,194	$96,459	n/a	n/a	$132,872	$59,497
6		$15,954	$104,175	n/a	n/a	$221,093	$115,092
7		$16,751	$112,509	n/a	n/a	$316,852	$170,966
8		$17,589	$121,510	n/a	n/a	$420,773	$227,112
9		$18,468	$131,231	n/a	n/a	$533,536	$283,521
10		$19,392	$141,729	n/a	n/a	$655,874	$340,187

Simple Payback: 3.9 years

Note:
1. 5% inflation rate used for operating cost
2. 8% inflation rate used for savings
3. 8% discount rate used for net present value

4.2.5 Impact Assessment, Gyro Automation

Material Flows

The present manual gyro packaging operation has sufficient capability to process all of the gyros which are released from the gyro repair shop. Since the number of gyros packaged in one day is limited to the number of gyros repaired and released for packaging, increasing the speed of the gyro packaging process would not result in a higher production throughput. In addition, the gyro packaging operation is a terminal operation in the sense that it does not feed its product directly into another operation. The packaged gyros are taken from the gyro packaging area and are either placed in storage or shipped. The automation of the gyro packaging process is expected to provide equal or better throughput over the manual process. Increases in throughput would be derived from the consistent pacing of the operation and increased orderliness of associated materials handling.

There is a case which warrants consideration. If the number of gyros released from the repair facility were to increase such that the automated system could not keep up, a backlog of unpackaged gyros would develop. One potential solution to this problem would be to allow the gyro packaging system to operate for more than one shift per day in order to catch up. Thus, the system might need to be operated for two or three shifts per day in the event of extraordinary flows, as in mobilization periods. Alternatively, a second work cell could be installed.

Vulnerability and Mission Capability

The effect of the automation of gyro packaging on the vulnerability and mission capability of the Distribution Directorate will depend directly on the system performance and reliability. The system must be capable of providing adequate performance under mobilization flow conditions. It must be easily and quickly repaired in the event of a system component breakdown, if the vulnerability and mission capability of the Distribution Directorate are not to be impaired. As with all automation, protection must take the form of a thorough and detailed training program for maintenance and operation. An adequate supply of repair parts is mandatory. Back-up, manual processing is also mandatory and requires routine training, exercises, and thorough documentation in the form of manuals. Additional warehouse space would not be required for manual processing as the existing work areas would be adequate.

Computer Systems

The proposed automated gyro packaging system would not need to communicate with the Directorate's information systems. All of the computation, program, and system control functions would be performed by the robot control system computer. At the end of each day the robot control system computer could transmit inventory control information to the appropriate Directorate information system, if desired. The implementation of the system would, therefore, not be expected to add to the burden of the already overloaded existing information systems.

Gyro Damage and Quality of Pack

The design of an automated gyro packaging system would not be complete without proper attention to safeguards to prevent damage to the gyros. Gyro damage could result from a number of circumstances. If the robot grasps the gyro in the wrong location, it may damage a delicate component. If the robot gripper grasps the gyro in the right location, but with too much pressure, damage may result. Incorrect gyro identification may result in damage. Slippage of the gyro in the gripper may cause damage if the robot control computer is unaware of the slippage. A gyro which slips out of the gripper is very likely to suffer major impact damage. An attempt by the robot to insert a gyro into the wrong TPO could damage it, or the gyro could be damaged in transit if the incorrect TPO does not protect it. Gyro damage may also occur through the malfunction of one of the pieces of hard automation, as well as from operator error, as in dropping a partially packaged gyro.

The prevention of damage to the gyro by the robot gripper is primarily dependent on the incorporation of tactile sensors in the gripping pads. The control computer can monitor the pressure and slippage information registered by the sensors, and can direct the robot gripper to provide corrective action before damage to the gyro occurs.

Potential damage to the gyros by the hard automation devices can be limited by the incorporation of sensors to detect incorrect placement or orientation of the gyros. Proper training and job experience will tend to reduce the number of gyros damaged through human error.

The quality of the packaging performed by the automated system should reflect improvements in consistency as compared to the quality of manual packaging. The overall quality of packaging might further be improved if alternative packaging techniques are found to be applicable. A foam-in-place process could be particularly promising. The foam-in-place process, using a robot, could be sealed off to prevent environmental objections. Incorporation of this process could dramatically reduce the number of TPOs needed to package the 45 different gyros, possibly from 23 to 5 or 10. The robot system could easily be adapted to this packaging process.

4.2.6 Advanced Gyro Packaging System

The near term proposed system for the automation of the gyro packaging task has been presented. In the near term system design, the operator was included to perform some of the work elements. The long term system design automates the tasks performed by the operator. The near term automated system could make up to four employees available for reassignment to more challenging areas. The automation of the remaining tasks could require a capital investment of approximately the same magnitude as the whole previous system. An extensive analysis would need to be performed before a decision could be made as to the benefit of such an advanced system.

In the previously proposed system, the operator performed the following functions:

- Obtain and locate gyros
- Identify gyro type
- Obtain TPO

- Prepare TPO
- Perform final TPO assembly, seal, and label
- Transport packaged gyro to holding area
- Service the hard automation equipment
- Monitor the overall system performance.

The automation of these tasks could be accomplished in a number of ways. One possible approach is described in the following paragraphs.

Obtain and locate gyros: the gyros are placed in partitioned sections in a tray on the top of a wire guided vehicle. The gyro identifications are keyed into the memory of the wire guided vehicle by repair personnel. The vehicle delivers the gyros to the gyro acquisition station.

Identify gyro type: The wire guided vehicle communicates the gyro type and location in the tray to the robot control computer when it presents the gyros at the acquisition station.

Obtain TPO, prepare TPO: The TPOs are stored in a prepared form in a multilevel conveyorized feeding system. When a gyro is selected by the robot, the control computer directs the TPO feeding system to release the appropriate TPO. The TPO is delivered to an additional station in the work cell where hard automation and the robot separate the TPO components and deliver them to the appropriate stations.

Perform final TPO assembly, seal, and label: Specialized interchangeable grippers are used for the robot to grasp the vacuum sealed box and insert it in the TPO slide pack. Hard automation devices complete the TPO assembly, seal, and label.

Transport the packaged gyro to the holding area: This is accomplished by conveyor or by wire guided vehicle, or both.

Service the hard automation equipment: Maintaining supplies of paper and vacuum seal bags are accomplished with hard automation. More complex service requires the talents of a human worker.

Monitor the overall system performance: The robot control computer monitors the robot and hard automation performance, reporting malfunctions to the human operator.

4.2.7 Conclusions for Gyro Packaging Automation

The gyro packaging robot system is desirable for a first installation of this type of automation. It is a cost effective application that is inherently low risk, using primarily commercially available equipment and requiring minimal development effort. It also is an application that would be minimally disruptive to surrounding operations, as it is the last task in the flow through the gyro repair facility. Start-up at reduced capacity would not present a bottleneck as manual packaging could be accomplished in conjunction with the system, until full capacity is obtained.

4.3 Feasibility Study for TAALS (Transporting Automatic Addressing and Labeling Systems) Automation

4.3.1 TAALS (Shipping) Operations

The TAALS weighing, cubing, and labeling process is an integral part of the shipping operations of the Distribution Directorate. The TAALS area is located in building 376, the central shipping facility for all orders originating at Warner Robins. Basic processes in the shipping area involve sorting, packing, labeling, routing, and accounting tasks. This feasibility study focuses on the final stages of packaging and labeling with the most important feature being the reduction of manual handling of information in the form of paperwork. Following is a brief description of the current operations in the TAALS section of shipping.

After materials are packed and routed, they must be labeled for shipping. The labeling process requires information, such as dimensions, weights, item descriptions, identification numbers, carrier, and destination for each parcel.

The on-line packers perform a variety of functions to generate a label while items are moved on the conveyor through the TAALS weighing and cubing devices. Each item uses the services of a keypunch operator, a CRT operator, the automatic label maker, a label placer, and an inspector. The following tasks describe each of the operator's functions:

The Keypunch Operator

1. Walks outside of TAALS area
2. Removes paper from the open envelope
3. Assigns a number to the container from 1-99 in chronological order
4. Writes assigned number on corresponding container
5. Writes assigned number on D-1348 document
6. Reaches a sufficient number of documents and punches information from document onto cards using the keypunch machine
7. Hands the stack of keypunch cards to the CRT operator
8. Places D-1348 documents back in the open envelope of the correct package.

The CRT Operator

1. Feeds keypunched cards, one at a time, into the card reader
2. Presses code letter for priority level
3. Answers various questions that appear on CRT screen regarding item
4. Places card in package envelope
5. Passes package through the automatic weigh and cube devices (volume measurement).

The Label Placer

1. Removes label from labeling machine
2. Places label on respective package
3. Checks weight information
4. Weighs item if it was too light to register on the weighing machine
5. Finds and writes address of destination if not given automatically.

The Inspector

1. Checks each package for proper packaging, routing, and labeling
2. Removes D-1348 if package travels LOGAIR
3. Checks for 4-foot drop regulation compliance.

From the TAALS area, these items must then be separated once again according to assigned carriers. This task is undertaken by the console operator who controls the pop-up roller conveyor which directs packages to other conveyor lines. During peak load periods, additional workers are used as "runners" to assist in the operation of up to three processing lines.

4.3.2 TAALS Automation Functional Requirements

The automation of TAALS in shipping could reduce labeling errors, increase the production throughput rate, and reduce the cost of weighing, cubing, labeling, and sorting of outgoing packages. The process can be broken down into functional requirements in the same way as was previously presented for the gyro packaging process. Each of the functional requirements represents an activity which can be performed by a material or information handling agent. Each of the functional items listed is accompanied by a short discussion of special considerations which apply to that item.

Functional Requirement: Generation and Application of DOD 1348, IBM Card, and LOGMAR Label to Item

The DO-33 computer system contains all of the information about an item which is printed on the DOD 1348 form. The information in this computer system is sufficient for the assignment of a transportation mode. It should, therefore, be possible to generate the form 1348, the IBM card normally created in TAALS, and a LOGMAR (Logistics Application of Automated Marking and Reading Symbols) bar code label at the location that the 1348 form is presently created. The packaging personnel who apply the 1348 form to the item can also place the IBM card in the plastic pouch with the 1348 form and apply the LOGMAR label. This operation would be performed prior to the transportation of the item to the TAALS area.

Functional Requirement: Item Identification

The item is transported from the packaging area to TAALS by roller conveyor. Just prior to entering TAALS, the item must be identified. The identification process includes determining if the item is a plastic tote containing parcels or if the item is free riding on the conveyor.

Functional Requirement: Weigh and Cube

All items passing through TAALS must be weighed and cubed prior to label generation and application. The weighing and cubing processes should be performed without retarding the continuous flow of items through TAALS.

Functional Requirement: Label Generation and Application

When the weight, cube, and transportation mode have been determined for an item, a shipping label can be printed. The label must be applied and laminated with a patch of adhesive plastic. The labeling device must be able to accommodate the variability of the size of the items.

Functional Requirement: Inspection

Each item must be inspected to determine if it was packaged properly, if the label is applied correctly, and if special labeling is required (hazardous, MICAP, etc.). The 1348 form must also be removed from the item if it is to be shipped air freight.

Functional Requirement: Sorting of Item by Transportation Mode

After each item has been inspected and released from TAALS, it must be sorted on the basis of its transportation mode. This could be accomplished by tracking the item in the handling system from the time of initial identification, or the item could be reidentified.

4.3.3 TAALS Material Characterization

The design of an automated material handling system for TAALS must begin with an understanding of the descriptive characteristics of the items which are to be handled. Maximum, minimum, and mean size and weight information is crucial to the specification of the handling equipment. The flexibility and softness of items bears directly on the approach taken in the implementation of an automatic label applying unit. The important results of the analysis are presented in the following paragraphs.

The flow of material released from TAALS was randomly sampled with data recorded as shown in Figure 20 (TAALS Weigh and Cube Data Sheet). The data obtained was entered into a STATPAK computer program data file on an IBM PC microcomputer. The STATPAK program was used to perform a statistical analysis of the data. Before the results of the analysis are presented, a word of caution is in order.

The statistical analysis of the data collected at TAALS should not be taken as definitive. Our sample size, 265 items, was relatively small compared to the total flow of material through TAALS. In addition, the sampling was performed in three sessions which were unevenly distributed within a two week period. A much more accurate sample could have been obtained if a larger number of items had been sampled over the course of a year. The size, scope, and duration of this project limited the amount of sampling which could be performed.

These cautions are not meant to discount the value of the statistical analysis, but merely to caution against any tendency to consider the results to be definitive. They provide useful information for the development of proposed automation systems, but, before a final design was established and an actual system was implemented, a more thorough sampling and statistical

Figure 20

DATA COLLECTION FOR TAALS MATERIAL CHARACTERIZATION

TAALS WEIGH AND CUBE DATA SHEET

NAMES: ______________________ (RECORDER)

____

TIME: __________ am/pm

DATE: __________

DESCRIPTION

ITEM TYPE: BOX / TUBE / BAG / FLAT / OTHER — COMMENTS

IRREGULAR SHAPE: RECTANGULAR / CYLINDRICAL / OTHER — COMMENTS

ACTUAL WEIGHT __________ LABEL WEIGHT __________

ACTUAL DIMENSIONS: — COMMENTS

LENGTH __________

HEIGHT __________

WIDTH __________

DIAMETER __________

ACTUAL CUBE: __________ LABEL CUBE: __________

FLEXIBILITY:	HIGH	MODERATE	LOW
SOFTNESS (COMPRESSABILITY)	SOFT	MODERATE	HARD

COMMENTS

LABEL LOCATION LIMITATIONS:

ACTUAL LOCATION AND ORIENTATION OF LABEL:

OTHER COMMENTS:

analysis would need to be performed. The complete data file, STATPAK codebook, and statistical results are presented in Appendix F of this report.

The most striking result of the statistical analysis is that there is a great deal of uniformity in the items. Greater than 98 percent were rectangular in shape. Almost 75 percent of the items were boxes, with another 22.6 percent being classified as flats--large flat envelopes. The mean weight was 10.2 pounds. The heaviest item sampled weighed 112 pounds. The mean length, width, and height were 18.1 inches, 12.7 inches, and 8.8 inches, respectively. The longest item measured 39 inches.

No useful information was obtained from the cube data because a large number of the labels showed the maximum permissible length-plus-girth for the item instead of its cubic volume. The greater majority of items, 78.5 percent, were considered hard to the touch, and a similar number, 80.4 percent, were classified as having low flexibility.

The most common transportation mode was air freight, 44.2 percent, with United Parcel Service carrying the next largest group of items, 20 percent. Only 8.3 percent of all items were classified as being MICAP or Express shipments. Most of the items, 47.9 percent, were priority "three." Priority "one" items comprised another 34.3 percent.

In addition to the individual descriptive data which was collected, a record was kept of the items which were in a tote and the items which were free-riding. The percentage of totes is important because it determines the percentage of items which would remain manually processed. Items in totes comprised 42.6 percent of the total material flow through TAALS. The remaining 57.4 percent represents the items which could be automatically processed except for a few unusual, free-riding items which would also need to be processed manually.

4.3.4 TAALS Proposed Systems

The automation of the TAALS area in shipping could provide significant cost reductions, but the implementation of a robotic system would require a moderate amount of hardware, software, and systems integration development. Because of this, implementation of this proposed system is seen as requiring more time than would be needed to implement the gyro packaging system.

Items normally flow from packaging directly into TAALS. Each item carries a form (1348) stuffed into an adhesive-backed transparent plastic pocket. When the item enters TAALS, the 1348 is removed, handled, and replaced in the pocket along with an IBM card which is generated in TAALS. One of the primary goals of the proposed TAALS automated system is to reduce or eliminate the handling of documents. All of the information on the documents is either already in a computer data base, or could be readily included in one. The system would be able to perform the necessary information processing functions without the need for the physical handling of documents.

The proposed system begins with the automatic generation of the IBM card and the LOGMAR label at the same location that the form 1348 is created and applied. This will generally occur in the warehouse that supplied the item, or in the consolidation area of shipping. The personnel who secure the form 1348 to the item would also apply the LOGMAR label and place the IBM card into the form 1348 plastic pouch.

The following paragraphs outline the proposed automated weigh, cube, and labeling system for free-riding items processed through TAALS. The processing of items in totes is also addressed. Although the items in totes are not handled automatically, this proposed system could also reduce the labor required to manually process these items. Figures 21, 22, and 23 depict the proposed concept.

The item is transported from the packaging areas to TAALS using the same conveyor system which is presently in use. If the item is in a tote, a tote detecting device would divert the tote from the main line onto a conveyor leading to the manual processing line. The presence of a tote could be determined in a variety of ways. One approach is to mark each tote with a stripe of fluorescent material. As the tote passes by an ultraviolet lamp, the stripe fluoresces. The fluorescence is detected by an optical detector which is filtered to exclude other colors of light. The optical detector activates the system which diverts the tote onto the manual processing feeding conveyor.

A bar-code reader would scan the top of the box for the LOGMAR bar code. If no bar code was detected, the box would be diverted to the manual pro-

Figure 21

AUTOMATION OF TAALS

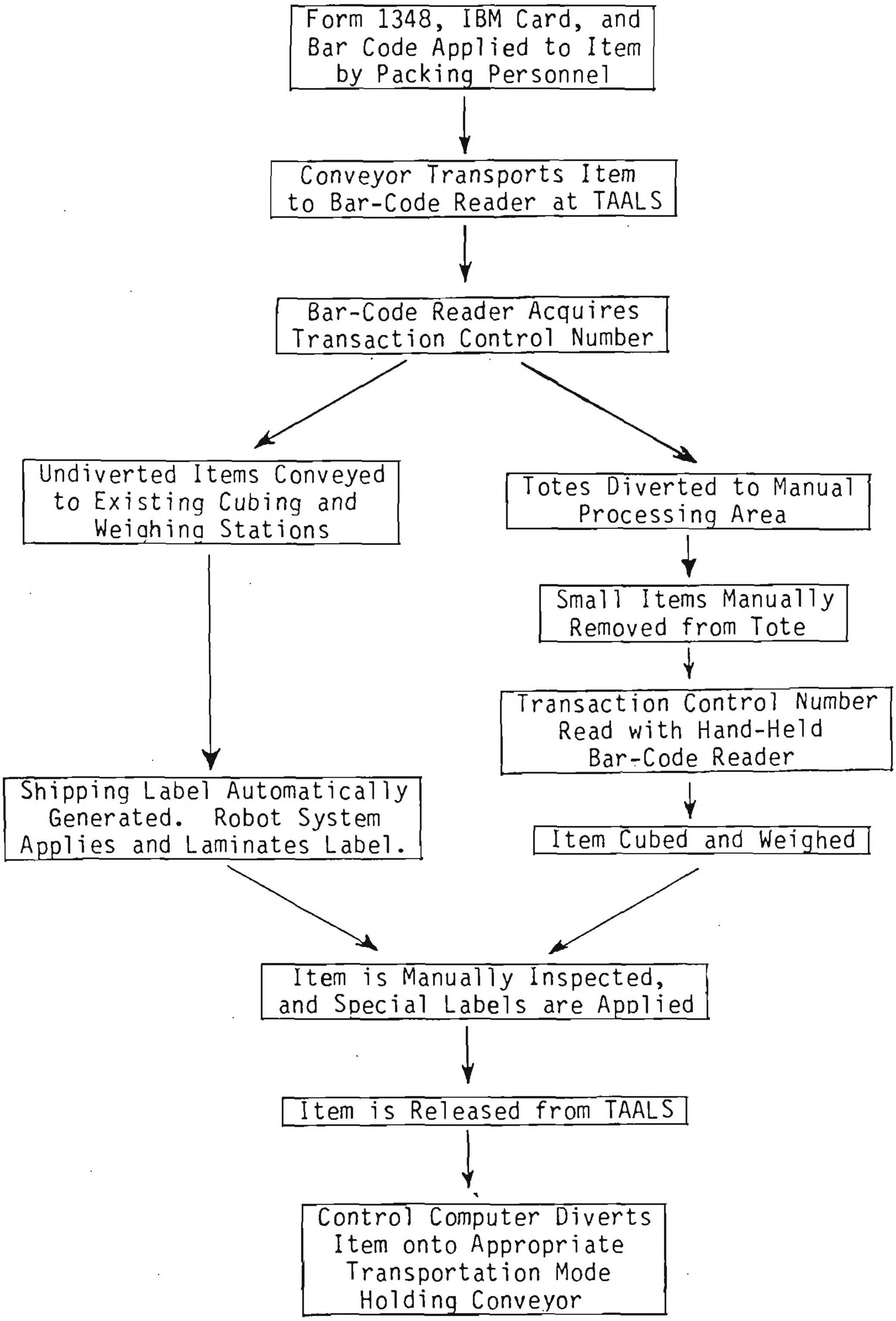
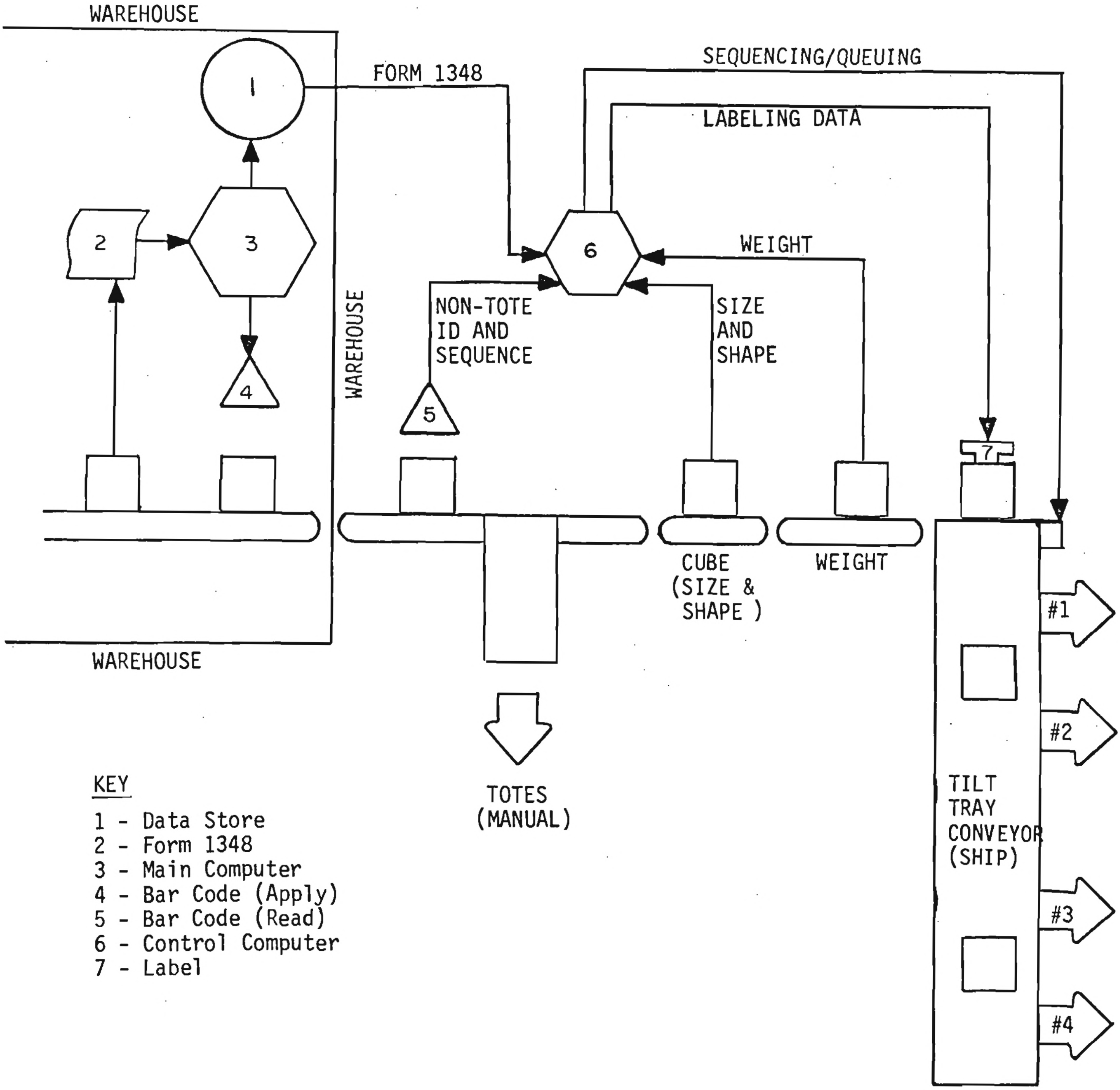


Figure 22

SHIPPING - TAALS

AUTOMATION OF QUEUING AND LABELING

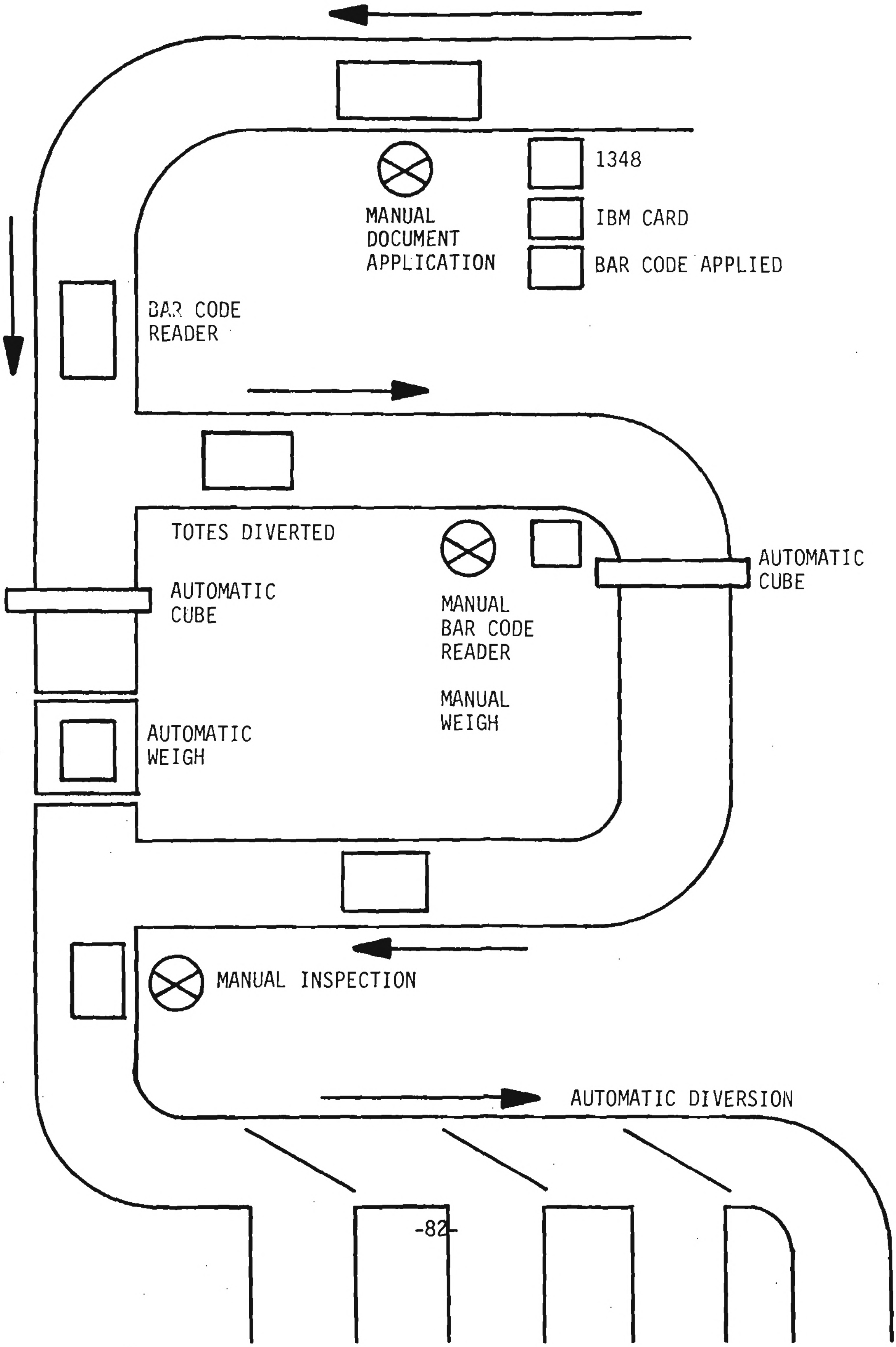


KEY

1 - Data Store
2 - Form 1348
3 - Main Computer
4 - Bar Code (Apply)
5 - Bar Code (Read)
6 - Control Computer
7 - Label

Figure 23

TAALS AUTOMATION LAYOUT



cessing area, just as totes are diverted.

The reading of the bar code would inform the TAALS computer system of the identity of the item. The TAALS control computer would then interrogate the DO-33 computer system to obtain the appropriate label information. This satisfies the functional requirement of item identification.

The item is then moved by conveyor to the cubing frame and weigh station. The existing cubing and weighing units can be used. The cubing and weighing units would transmit their descriptive information to the TAALS control computer, which would then direct the generation of a label. The functional requirements of weighing and cubing and part of label generation are satisfied.

The label is produced on an automatic printer/laminator. The printer/laminator has the robotic flexibility to apply the label to the side of any parcel which passes through the system. The parcel dimensions, having been obtained from the cubing frame, would be used by the labeling device to determine the correct application position as the item is carried on the belt conveyor. This unit satisfies the functional requirements of label generation and application. This unit, as proposed, is not commercially available, and would require both hardware and software development. Somewhat less automated labeling devices are presently being marketed, however.

It should be noted that the "robotic" system envisioned here follows the broad definition posed by the Robot Industries Association and may not take the traditional form of the "arm and gripper" type manipulator. Nonetheless, the automatic labeler would require the flexibility to address various parcel sizes and shapes, and would be reprogrammable, therefy, fulfilling the requirements of a robot system.

All items must be inspected prior to being released from TAALS. This process is accomplished by a human inspector. The inspector examines the item to determine if the label is applied correctly. He applies any special labels required, and removes the form 1348 from the item if it is being shipped by air freight. When he is satisfied with the condition of the item, it is released from TAALS. The functional requirements for inspection are thus accomplished with no changes from the present operation.

The TAALS control computer would track each item from the time the bar code was initially read. When the item was released from TAALS, the computer would communicate its transportation mode to the sorting conveyor controller. The sorting conveyor would then divert the item to the appropriate transportation mode holding conveyor. This part of the proposed system would utilize the equipment presently in use. The sorting information is currently entered into the sorting conveyor by the "kicker" operator. The TAALS computer control system would be able to bypass the need for this information input since it would communicate with the conveyor control system directly. The functional requirement for sorting is accomplished in this manner.

The manual handling of totes follows the same general sequence of operations as the automatic handling of nontote items. The items in the totes are manually removed and the bar codes are scanned with a hand-held bar-code reader. The items are then passed through a cubing frame and are manually weighed. The cubing frame and weighing device communicate directly with the TAALS computer, which then generates a label. The label is manually applied and the item is placed in a tote. The tote is transported to the inspection station, the inspection is performed, and the item is released from TAALS. Sorting according to destination mode is accomplished in the same manner as for the nontote items.

4.3.5 Economic Analysis

The preliminary specifications for the equipment in this system are presented in Tables 7 and 8. Cost estimates were derived from vendor quotations, engineering estimates, and documented historical experience with robot systems. A ten-year, life-cycle economic analysis was performed as recommended by Distribution Directorate management. Currently accepted inflation rates for costs and labor savings (5% and 8%, respectively) were incorporated into the annual cash flows. A cash flow discount rate of 8% to reflect the current Federal cost of capital. This discount rate did not materially affect the outcome of the analysis over a range of 0% to 15%. No tax effects were utilized in this analysis as this would be a federally funded project, if undertaken.

The specifications for the robot and associated equipment were based on a characterization of the materials which flow through the TAALS area, as previously described. The data analysis appears in Appendix F of this report.

Budgetary quotations for the bar code reader and peripheral items were solicited from vendors. Costs used were upward rounded averages for conservatism and contingencies. The development cost for a prototype of the automatic labeling unit was based on the cost of available equipment and our experience with prototype hardware and software development.

Installation costs are subjective engineering estimates based on experience with the equipment, installation, and advanced automation start-up. Published guidelines for robot installations of this type suggest that a complete turnkey installation will cost three to four times the cost of the robot. Given that the robotic portion of this system (the automatic labeling unit) might cost $40,000 after initial prototype development, our estimate falls into the high end of this range.

Operating costs were also estimated based on published experience with these systems. Maintenance costs for a complete system usually average 10% of the cost of the robot. Utilities costs are usually negligible and training costs can vary widely depending on the number of operators and their associated skill levels.

The basis for direct labor savings in the TAALS area derives from reduction in the direct touch labor required to locate, read, and enter information to keypunch operator stations, to enter information at the CRT operator stations, and to apply printed labels to parcels.

Detailed MTM (Motion and Time Methods) studies for these operators' tasks have been performed by the engineering staff at the Distribution Directorate. As an example, the standard labor hours for one work cycle at the keypunch operator's work station is .07 hours or 4.2 minutes.

At the current level of throughput, the TAALS area is in operation one shift per day. At peak flows, three lines of five or six persons each are in use, while at other times, one line is adequate. In general, one line consists of the following:

- 1 keypunch operator
- 1 card sorter/CRT operator

- 1 label applier
- 1 bulk operator
- 1 runner
- 1 inspection.

Other persons involved in peripheral operations bring the maximum labor force in the TAALS area to 24 workers in the peak periods.

The bar code reader is capable of scanning at a rate of 2 codes per second although manual operation will slow the task to about 2 seconds per item on the average. We anticipate a 5 second lag for processing time and data transfer to the label making equipment and a 10 second cycle for label printing and application.

Based on the foregoing data and current work force levels, we anticipate a total reduction in direct labor of approximately 8 workers (33%) per shift.

- 2 keypunch operators
- 2 CRT operators
- 2 label appliers
- 2 runners.

It is also possible that further reductions in direct touch labor could result in the peripheral operations as a result of the increased orderliness and pacing in the TAALS area. Therefore, a small productivity improvement of 5% was subjectively estimated and included in the annual savings.

TABLE 7

TAALS AUTOMATION ECONOMIC ANALYSIS

A. Equipment Specifications and Capital Costs	
Bar Code Reader: Permanent Mount Code 39, 13 digit (LOGMARS specifications) 60 to 100 fpm item motion with pependicular presentation 8 inches or less from reader Programmable firmware for code recognition 600 scans/second	$ 12,000
Light Pen Hand-Held Bar Code Reader with Keyboard:	$ 2,000
Automatic Labeling Unit: (cost includes development) Automatic printing, applying, and laminating of standard DOD shipping labels Ability to adapt to item size variations 15 labels/minute speed	$140,000
Dedicated Processor and Interfaces:	$ 50,000
TOTAL EQUIPMENT COSTS:	$204,000
B. Installation Costs	
Facilities Preparation Power and Utilities Labor	$ 8,000
Engineering and Software	$ 20,000
Equipment Installation	$ 5,000
Systems Integration	$ 5,000
Test and Debug	$ 5,000
Training Program (1st year): Operator Maintenance	$ 4,000
Spare Parts Inventory	$ 2,000
TOTAL INSTALLATION COSTS:	$ 69,000

TABLE 7

TAALS AUTOMATION ECONOMIC ANALYSIS
(Concluded)

C. Operating Costs (Annual)

Utilities:	$ 200
Maintenance:	$ 4,000
Training:	$ 1,000
Programming:	$ 1,000
TOTAL ANNUAL OPERATING COSTS:	$ 6,200

D. Annual Savings

Twenty-four GS4 personnel are currently authorized for TAALS. The average benefits-loaded pay for these workers is approximately $8.50/hour. It is estimated that eight of these employees could be reassigned to other areas if the proposed system is implemented.

Direct Labor: 8-GS4 @ $8.50/hr (benefits loaded rate) x 2,000 hours/yr	$136,000
Productivity Improvement @ 5%	$ 6,800
Materials Reduction	$ - 0 -
Damage Reduction	$ - 0 -
TOTAL ANNUAL SAVINGS	$142,000

Table 8

TAALS Automation

Ten Year Life Cycle Economic Analysis

year	capital	operating cost	savings	depre-ciation	tax	accumulated savings	net present value
0	$273,000					($273,000)	($273,000)
1		$6,200	$142,800	n/a	n/a	($136,400)	($146,519)
2		$6,510	$154,224	n/a	n/a	$11,314	($19,878)
3		$6,836	$166,562	n/a	n/a	$171,040	$106,918
4		$7,177	$179,887	n/a	n/a	$343,750	$233,865
5		$7,536	$194,278	n/a	n/a	$530,492	$360,958
6		$7,913	$209,820	n/a	n/a	$732,399	$488,194
7		$8,309	$226,606	n/a	n/a	$950,696	$615,568
8		$8,724	$244,734	n/a	n/a	$1,186,706	$743,077
9		$9,160	$264,313	n/a	n/a	$1,441,859	$870,717
10		$9,618	$285,458	n/a	n/a	$1,717,698	$998,484

Simple Payback: 2.2 years

Note:
1. 5% inflation rate used for operating cost
2. 8% inflation rate used for savings
3. 8% discount rate used for net present value

4.3.6 Impact Assessment

Impact on Production Throughput

The automation of the TAALS area could substantially improve production throughput. The primary time savings is gained by the elimination of document handling and label applications. These tasks are automated and also partially shifted to an activity which occurs upstream of TAALS. The partial shifting of the document handling should not reduce throughput in upstream process as it would not add significant additional motions.

Impact on Vulnerability and Mission Capability

The present TAALS system, along with most routine operations of the Distribution Directorate, depends on information systems which are subject to failures. The proposed system would also be vulnerable to computer failure at a somewhat greater level than the present manual system. The present system does not halt if the DO-33 computer system shuts down, but only if the TAALS computer is down. The proposed system would be vulnerable to the failure of either computer since the TAALS computer must communicate with the DO-33 for label information.

In the event of failure of the automatic bar code reader or the automatic labeling unit, all of the items could be manually processed in the same manner as the manual tote processing.

The mission capability of the Distribution Directorate should be enhanced by the implementation of the proposed system. The maximum throughput of material should be substantially increased because of the streamlined processing of items. This provides a margin of safety in the event of a dramatic increase in required throughput, as would occur in mobilization periods.

Impact on Computer Systems

Substantial portions of manual information handling is being shifted to the computer systems. Both the TAALS computer and the DO-33 computer system would need to process and transmit more information than at present. A new computer system (AWS) will be installed in the near future. This system should have sufficient capacity to be able to handle the increased information flow if the TAALS automation is implemented. Development efforts for this concept should include specific interfacing requirements for the new AWS system and implementation should also be scheduled after the new system is installed.

Quality

The quality of the weigh, cube, and labeling performed by the proposed system should be equal in quality to the present manual process. The quality of label placement by the proposed system may be superior to the manual process because of more consistent label location.

4.3.7 Conclusions for TAALS Automation

The robotic system for automation of the TAALS area is cost effective even with the moderate development cost ($100,000) included for the labeling unit. The physical configuration of the labeling unit would probably not be the "arm and gripper" configuration typical of most commercially available industrial robots, but nonetheless would be a robotics system with flexible capabilities.

The interfacing of the robotic system and other computerized information systems (such as the DO-33 system) would be a major milestone in developing robotics know-how in the Directorate operations. There are as many as five different computerized information systems currently in use and the trend for the future is to add additional capacity and sophistication in this area.

The label application unit calls for the development of somewhat unique dexterity in a robotic system to handle thin, flexible, document-like materials. The accomplishment of this goal could potentially open the door to automation in other document handling tasks where hard copy requirements are expected to persist into the foreseeable future.

4.4 Feasibility Study for Sortation in the Air Freight Terminal

4.4.1 Sortation

The feasibility studies presented for Gyro Pack and TAALS are significant in that they address two fundamental requirements for initial use of robotics type automation:

1. Pick the first application on the basis of ease of installation and sound economic benefit.

2. The communication of robotics systems with information systems for control and planning is a fundamental requirement for further use of these systems.

However, the long range potential for robotics in distribution complexes revolves around the notion of sortation as a basic work element. Sorting has the functional requirements of locating, singulating (separating), acquisition, orienting, and diverting (short movements). The process is, in fact, so basic to other tasks that it can easily be overlooked as a task in itself. Yet, because sorting is so fundamental to most of the manual materials handling tasks in distribution operations, the long range use of robotics depends on developing capabilities to address this problem.

Sorting has been referenced in many of the process descriptions for various distribution operations described thus far in the report. As further evidence of its importance, our detailed observations of the examination of the WICS (Warehouse Inventory and Control System) warehousing operations are submitted at the end of this section. This is the most sophisticated and automated facility in the Distribution Directorate. The manual tasks that are amenable to further automation each embody the problem of sortation.

The difficulty posed by the task of sorting in distribution operations is the extreme variability of items to be sorted. The requirement to adapt to characteristics of a different material item for each cycle, stretches the flexibility aspects of a robot system to its limit. While it might be argued that robot systems are not intended for "full flexibility," but rather for "batch" operations, the trend of capabilities and developments is unmistakenly toward that end. For the manual tasks to be automated in distribution operations, that capability will be mandatory.

Solving all of the complex issues of object recognition, data base management, gripper dexterity, adaptive control, and artificial intelligence (expert system) will require a long-range dedicated effort. It further requires a structured research plan that builds one fundamental capability upon another in building-block fashion to achieve the goals set forth.

The feasibility study for sorting in the Air Freight Terminal presents a possible starting point for just such a long term research effort. The variability of items and functional requirements are significantly contained to allow for development efforts to proceed in a structured fashion. Advances made in this application could be used as a basis for further expansion into other more variable operations.

A final note is in order regarding the cost benefit expected for this feasibility analysis. Most sorting tasks in distribution operations require full time direct touch labor and are expected to show positive cost effectiveness when automated. The site in the Air Freight Terminal is not a good selection for cost effectiveness because of the low level of direct touch labor dedicated to the task, sometimes as low as 20% of one worker's time per shift. Furthermore, the sorting task in this application is usually quite efficient as many of the parcels are pre-oriented for information acquisition. Most other sorting tasks are highly inefficient in the utilization of direct labor because of the random orientation of items being sorted and the random location of information used for the sorting decision.

The sorting application in the Air Freight Terminal is selected, then, not for an anticipated cost effectiveness, but at a site to begin development efforts that will lead to those sorting tasks that will be highly cost effective. The sorting application in the Air Freight Terminal can more readily be appreciated as an on-site robotics sorting laboratory to test prototype hardware and software that has progressed to the "proof-of-concept" stage.

4.4.2 Air Freight Operations

The air freight operations center, building 127, handles all material shipped or received by air. In-transit material (cargo that must be transferred from one aircraft to another) is also processed in this terminal. The material handled can be separated into three classes: free flow cargo, special handling cargo, and documented cargo.

The air freight process involves the major tasks of sorting, palletizing, depalletizing, aircraft loading and unloading, and bulk cargo handling. The specific procedure used to handle a given item is determined by its classification and priority. The handling procedures are designed to maximize safety and efficiency and to minimize transportation delay time.

The following paragraphs summarize the classification of each cargo type and present descriptions of the tasks performed on the cargo as it sorted and passed through the air freight system.

Cargo Classifications

Free Flow

Cargo sent by "free flow" is not tracked or documented as it passes through the system. Once released for shipment by the originating base, the location of materials within the system ithe ultimate destination. The free flow concept is very similar to the U.S. Postal Service. A package is given a label which indicates its point of origination and its ultimate destination, and its progression to that destination is largely insured by the first-in, first-out design of the cargo handling system.

All cargo which does not require special handling or which can not qualify for documented handling status is sent free flow.

Special Handling Cargo

Materials which require special handling include cargo classed as MICAP/999, hazardous, classified, weapons, bulk cargo, and pilferable items. These items are not allowed on the material handling conveyor lines, and must be individually delivered to their bins on the floor of the pallet handling area. Each type of special handling material is kept in a separate bin. Hazardous materials include acids, bases, and other dangerous chemicals, as well as radioactive materials. MICAPS cargo is separated into holding bins on the basis of destination group. Classified and pilferable items are held in a security cage. Weapons and explosives are secured until shipment in three different bunkers according to their explosive classification. Bulk cargo is delivered to an outdoor location which has both sheltered and unsheltered holding and processing areas.

Documented Cargo

Documented cargo includes all items which require special handling, as well as Navy cargo, MAC export/import, and cargo having specially designated project codes. These items must be declared on all manifests, both incoming and outgoing, and must be date stamped during the palletizing and depalletizing operations. The documentation procedure tracks their progress through the air freight handling system, so their position within it can be determined at any time.

Cargo Handling Tasks

Sorting

All material which is carried by the material handling conveyor system is sorted. A single sorting station handles the sorting of all incoming, outgoing, and in-transit conveyorable material. Bulk cargo and special handling cargo do not pass through the sorting station.

Outgoing material, cargo originating at WRALC, is received by conveyorized van at the air freight receiving dock. The cargo is transported by conveyor from the van to a holding conveyor. Each piece is manually checked to determine if it will require special handling or if it can be handled by the conveyor system. While the air freight personnel checks the cargo and separates out special handling items, this person also orients the items so their labels will be in the proper position to be read by the person at the sorting station.

The oriented parcels are transported by conveyor to the sorting station. The destination code for each item is read from the label as each item is presented to the sorting operator. The operator then keys a numerical code, corresponding to the holding conveyor number, into a keypad to direct the tilt tray sorting device to carry the item to the appropriate holding conveyor. The translation from the destination code to the holding conveyor number is accomplished through the use of a chart.

Incoming and in-transit cargo is also sorted at the sorting station, but it is not pre-oriented before it arrives at the sorting station. The sorting station operator must orient these items as presented, read the destination code, replace the item on the conveyor, and key in the holding conveyor number.

Free flow and documented items are not handled differently in the sorting operation.

4.4.3 Air Freight Sorting Functional Requirements

The air freight operations center incorporates a large amount of fixed automation to facilitate the rapid movement and processing of air freight cargo. Human controlled vehicles are integrated into the material handling system for functions that are not easily accomplished by fixed automation.

With one exception, all of the major tasks performed in the air freight terminal are too complex to be economically automated to a higher degree than presently exists. Sorting is the only manual task which may be relatively easily automated.

All of the material processed through the material handling system at air freight passes through a single sorting station. The tasks performed by the sorting station operator form the basis for the establishment of the functional capabilities for the sorting operation.

As in the two previous analyses, each functional capability will be accompanied by a brief description of important considerations which relate to it.

Functional Requirement: Acquire Item

Physical control of an item is a prerequisite to performing any handling function on it. An item is acquired if it is within the control of the automated system. Locating an item is a subset of this task which has complexity dependent on the structure of the process.

Functional Requirement: Orient Item

If the sorting criterion is based on information attached to the surface of the package, the information is likely to be on only one face of the item. Acquiring that information to make a sorting decision requires that the information be visible. Orientation of the item will be necessary if the information acquisition system does not have the flexibility to see all sides of the item.

Functional Requirement: Present Item to Information Acquisition Device

An oriented item must be brought into the active region of the information acquisition device for the information to be obtained. This will be a part of the orientation capability if the orientation is performed within the active region of the information acquisition device.

Functional Requirement: Acquire Information

Information acquisition can be complicated by extraneous information present on the package. An optical character reader would need to be able to discriminate the destination code from the other information on the label.

Functional Requirement: Feed Item to Sorting Device

Once the sorting decision information has been acquired, the item must be fed to the sorting device.

Functional Requirement: Perform Sort

The sorting device must be able to accurately perform the sort of the item based on the acquired information. A sortation process will always require the transportation of the item. The item must be maintained within the control of the sorting device until it is released at its destined location (diverted).

4.4.4 Air Freight Material Characterization

The characterization of the material handled by air freight was performed by extracting the material characteristics of all items going to air freight from the data collected at TAALS. This data does not represent a complete cross section of the material processed through air freight. It is only a limited measure of the air freight material which originates in WRALC shipping. Not included in this data are WRALC destinating items and in-transit items which arrive at air freight from other bases. A thorough analysis of the air freight sorting problem would require the inclusion of these items in the statistical analysis. The complete results of the statistical analysis are presented in Appendix F.

The items which are handled by air freight do not differ markedly from the items previously considered for TAALS. Part of this is because of the large number of items processed through TAALS which are to be shipped by air freight (over 44 percent). The air freight items are even more uniform than the general flow of items through TAALS.

Over 79 percent of the items were boxes, and 96.6 percent were rectangular. The nonbox items were almost all rectangular flats. The mean weight was 12.5 pounds, and the mean length, width, and height were 18.5 inches, 12.7 inches, and 8.9 inches, respectively. Almost 85 percent of the items were ranked hard to the touch, and a full 88 percent were considered inflexible.

The general picture of an item processed through air freight is that of a rigid currogated cardboard box on the order of one cubic foot in volume, and weighing 12.5 pounds. An item of this description is relatively easy to handle with automated equipment.

4.4.5 Air Freight, Proposed System

The development and testing of an automated sorting system in the air freight terminal would be an important step for future robotic applications. It is one of the best defined and tightly constrained sorting activities in the Distribution Directorate operations. The lessons learned through the implementation of automated sorting in air freight could be expanded to other cost effective sorting applications.

The following brief outline provides a concept for a system to automate the sorting task in air freight. Many other approaches could be taken to the solution of this problem.

The final design would necessarily be derived from exploratory research leading to proof of concept prototypes. However, for the purposes of economic analysis, we propose a system that is based on state-of-the-art concepts and ongoing research.

Figures 24, 25, and 26 depict the major components and layout of the system.

Items are received at the sorting station using the existing conveyor system. These items are assumed to have been bar-coded at TAALS or from other shipping locations.

The primary function of the robotic sorter is to locate and acquire each parcel and to move it to the appropriate location on the tilt tray conveyor, commensurate with its destination.

The reading of the bar code and acquisition of the distribution code may require presentation of the parcel to the bar code reader after determining the proper orientation of the bar code on the parcel. However, a bar code reader that is able to optically scan all sides of the parcel is a development item under consideration.

The destination code may not be part of the standard bar code used in shipping, therefore, it may be necessary for the control computer to communicate with the DO-33 computer for this information.

Once having acquired both the parcel and the destination code, the robot sorter would interact with the tilt tray controller. By sequencing their motions, it would place the parcel in the correct location on the conveyor for delivery to the appropriate holding area.

The fundamental problems of locating and acquiring a different size and weight object for each sorting cycle are reduced in this application by the reduced variability in parcel sizes and their relative consistency in shape and stiffness. The characterizations of the materials was presented earlier. Even so, accomplishing this highly unstructured task would require developments of advanced vision capabilities, ranging sensors, and adaptive software

Figure 24

AIR FREIGHT AUTOMATION

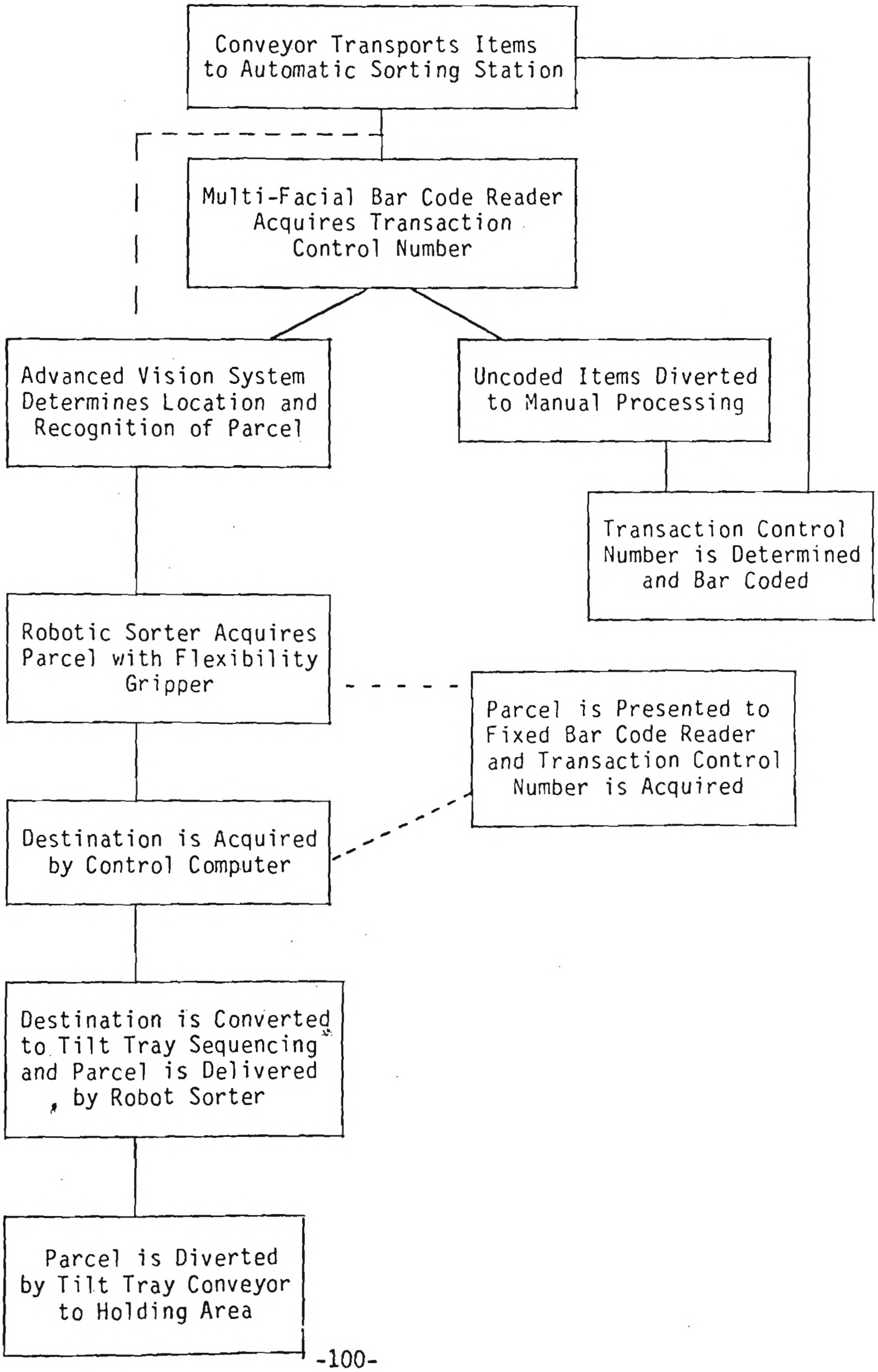
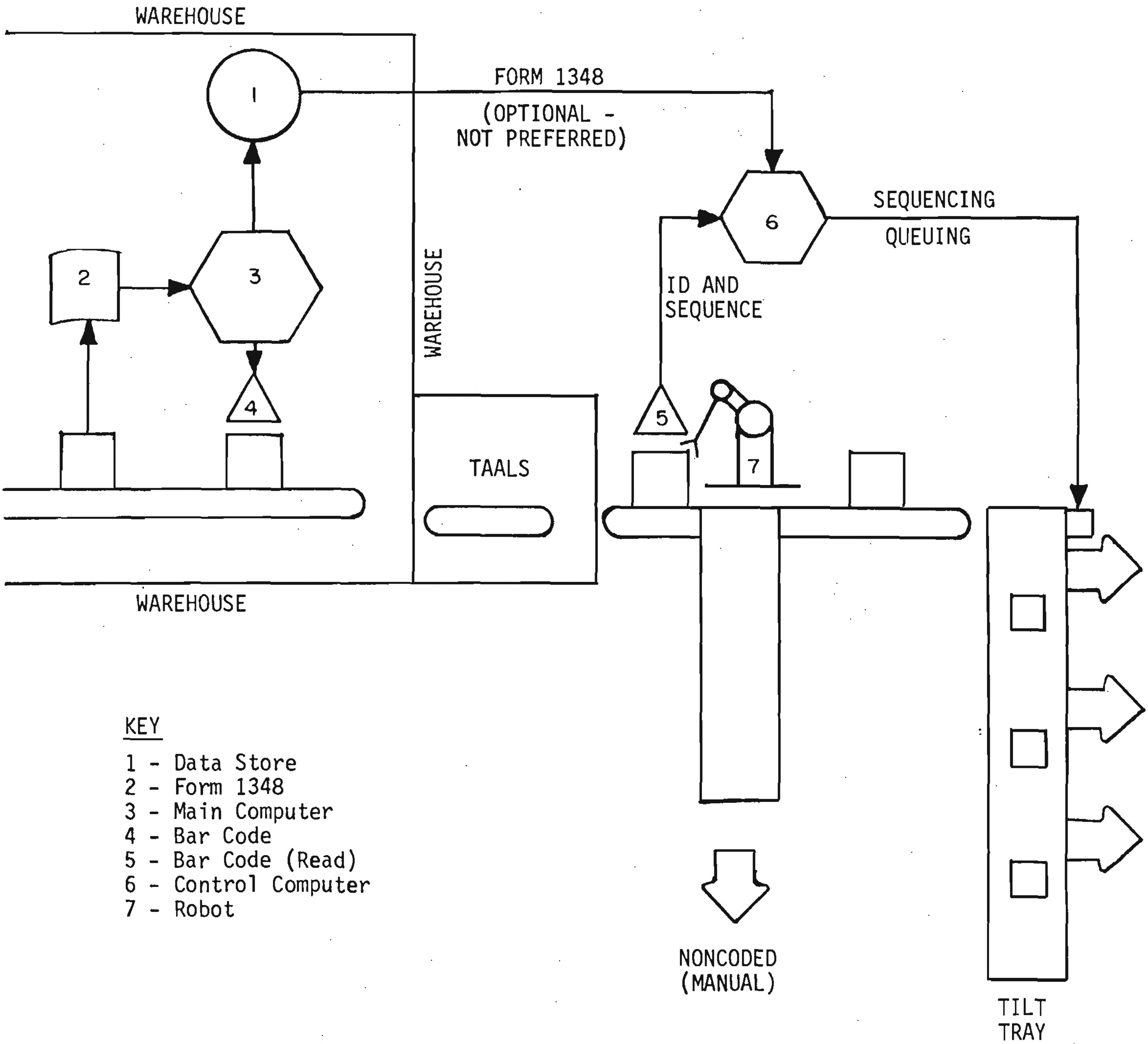


Figure 25

AIR FREIGHT
SORTING AUTOMATION

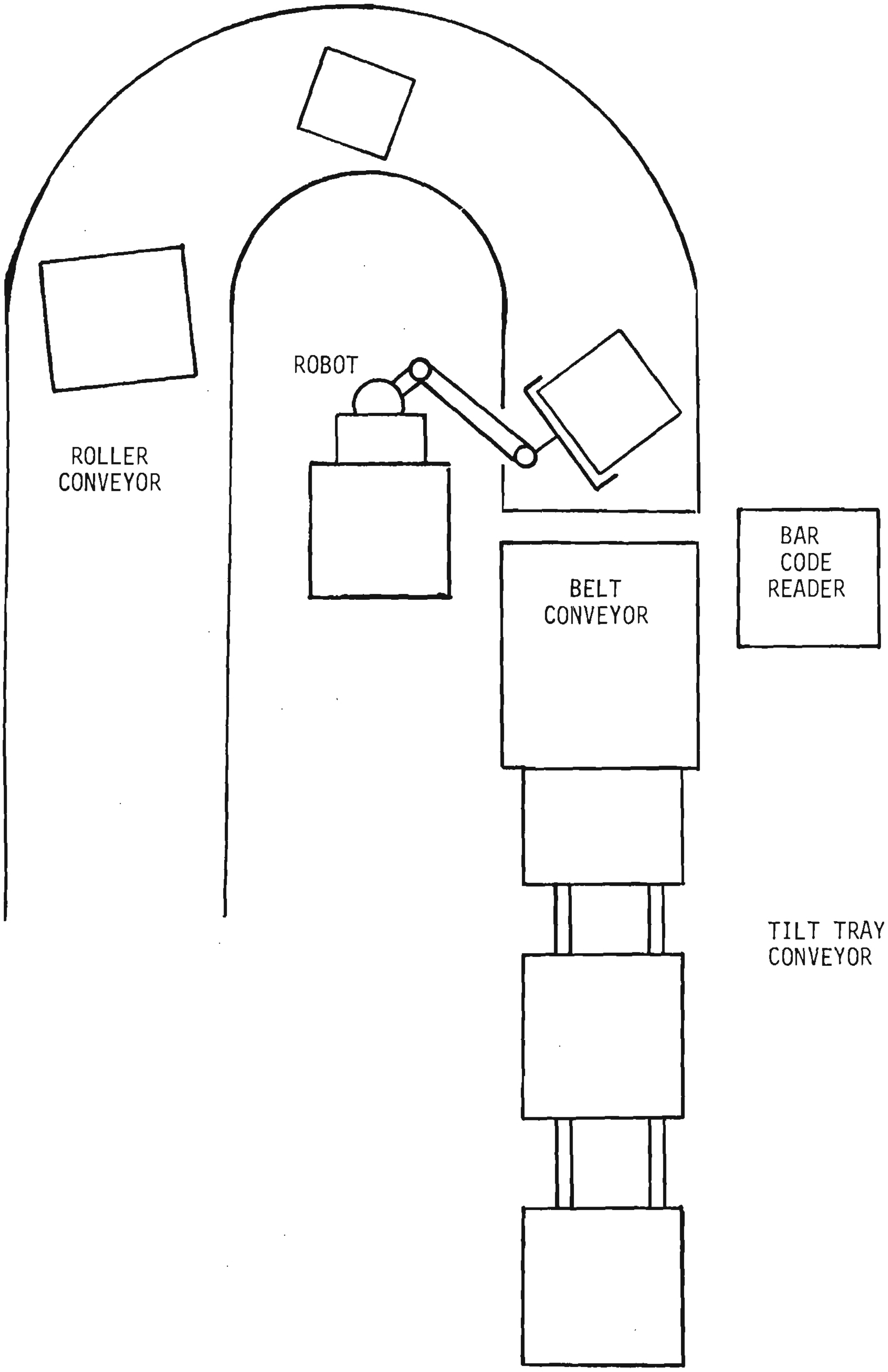


KEY

1 - Data Store
2 - Form 1348
3 - Main Computer
4 - Bar Code
5 - Bar Code (Read)
6 - Control Computer
7 - Robot

Figure 26

Air Freight Automation
Physical Layout



(expert systems). The order of magnitude of the problem should be within achieveable bounds given the reduced variability of the items to be manipulated.

Research and prototype development would also be required for highly flexible end-of-arm tooling to accommodate the range of shapes and sizes. Again, the reduced variability puts this development into an attainable category.

As previously mentioned, presentation of the parcel to the bar code reader would not be required, given the development of a multi-facial bar code reader. Concepts for a reader that can optically scan all sides of an item simultaneously or sequentially have been advanced and appear technically plausible.

Finally, the software required for the control computer to interface all of the items in the work cell would require a substantial development effort. Because of the processing requirements for recognition and adaptive acquisition of different items, efficient control software would be a desirable goal to maintain high throughput rates.

It is anticipated that the development of the capabilities to accomplish this sorting task would extend over several years. The knowledge gained from these efforts, however, would be highly transferable to other sorting tasks and would form the basis for efforts to add increasing capabilities for the more complex sortation operations. These steps are necessary to achieve the level of flexibility needed to accomplish tasks such as automated bin-picking in the distribution complex of the future.

4.4.6 Economic Analysis

Because the application was, in essence, selected to perform as an on-site "laboratory" rather than for anticipated cost effectiveness, a life cycle cost/benefit analysis was not deemed appropriate. Instead, the estimates provided reflect system and development costs as separate items to provide a benchmark for the magnitude of effort needed to address the sorting problem. These estimates are more subjective and tentative than those presented for the previous two studies as many of the capabilities required are not yet commercially available.

Furthermore, the undertaking of this application should represent only a first step toward achieving the capabilities required for the sorting tasks in other distribution operations that would be cost effective. The high cost of development would be amortized over many other cost effective applications in the Warner Robins Distribution Directorate and other Air Logistic Centers, as well. Table 9 presents our best estimates for this research effort.

TABLE 9

AIR FREIGHT AUTOMATED SORTING SYSTEM

A. Equipment Specifications and Capital Costs

Robot and Control System Jointed Arm (Revolute) Robot Maximum payload: 120 lbs Arm's extension: 5 feet or more Programmable controller (continuous path)	$150,000
System Control Computer Distributed processing operating system 2 MB memory Hard disk drive	$ 50,000
Advanced Vision System Recognition software Dedicated processors Ranging sensors Data base storage	$200,000
Flexible Gripper Boxes and flats Loads: 120 lbs maximum Sizes: 2 to 40 inches	$ 25,000
Bar Code Reader Permanent mount Code 39, 13 digit 60 to 100 fpm item motion with perpendicular presentation 8 inches or less from reader Programmable firmware for code recognition 600 scans/second	$ 12,000
Multi-Facial Bar Code Reader (Optional)	$ 30,000*
TOTAL EQUIPMENT COSTS*	$437,000 to $455,000

*Excludes development costs for advanced capabilities.

TABLE 9

AIR FREIGHT AUTOMATED SORTING SYSTEM
(Continued)

B. Installation Costs

Facilities Preparation	$ 15,000
Engineering and Software	$ 20,000*
Equipment Installation	$ 10,000
Systems Integration	$ 20,000*
Test and Debug	$ 20,000*
Training Program (1st year)	$ 5,000
Spare Parts Inventory	$ 10,000
TOTAL INSTALLATION COSTS*	$100,000

*Excludes basic research and development for advanced capabilities.

C. Operating Costs (Annual)

Utilities	$ 1,000
Maintenance	$ 30,000
Training	$ 2,000
Programming	$ 2,000
TOTAL ANNUAL OPERATING COSTS	$ 35,000

TABLE 9

AIR FREIGHT AUTOMATED SORTING SYSTEM
(Concluded)

D. Development Costs

Multi-Facial Bar Code Reader: 2 man-years, research professionals Prototype equipment Laboratory materials 18 month duration	$300,000
Advanced Vision System 4 man-years, research professionals Laboratory materials (Equipment cost excluded - to be furnished as final design prototype) 30 month duration	$450,000
Flexible Grippers 1 man-year, research professional Prototype equipment Laboratory materials 18 month duration	$130,000
Adaptive System Control Software 4 man-years, research professionals Computer time Laboratory materials 30 month duration	$480,000
TOTAL DEVELOPMENT COSTS	$1,360,000

E. Annual Savings (Not Utilized)

The Air Freight Terminal operates 24 hours per day in two 12-hour shifts. The heaviest traffic occurs during the night shift. Because personnel rotate task responsibilities and process the flow of materials in a batch mode, there is not a person assigned to the sorting task at all times. Estimates of man-hours per day for this task, derived from interviews with air freight personnel, are from 8 to 10 man-hours per 24-hour day. Savings for automation of this task are in the form of direct labor only as excess capacity exists and closing are materials reduction are negligible. Savings from misrouted items requiring reshipment were not estimated at this time.

Direct Labor 1 GS4 @ $8.50/hr (benefits loaded rates) x 10 hrs/day x 250 days/yr	$ 21,250

4.4.7 Impact Assessment

Impact on Production Throughput

The automation of sorting in air freight would improve production throughput for this individual task, but would have negligible impact on the overall throughput for the air terminal operations. This is because materials are processes in a batch mode and excess capacity exists throughout the various operations over the course of the work shift. Restructuring of the operation to take advantage of the capabilities in sorting might result in overall productivity increases in the form of reduced shift duration, but this depends on the flexibility of scheduling aircraft arrivals.

Impact on Vulnerability and Mission Capability

Vulnerability to system failure is greater than in the present operation because of increased use of computer systems and material handling automation. As in all military operations, back up capability is assured by maintaining a trained labor force that is able to assume responsibility with manual operation.

Mission capabilities would be enhanced in the form of increased surge capacity for mobilization periods. This is particularly true if the operation is restructured to take full advantage of the sorting capacity. In the long range perspective, the ground breaking developments undertaken for this task could have far reaching impacts on mission capabilities for the overall distribution operation. The technology developed would be highly transferable to other tasks throughout the Directorate and in other Air Logistics Centers.

Impact on Computer Systems

This system is not expected to place an overburdening load on other distribution information systems, particularly in light of the upcoming AWS installation. Development efforts would include specific interfacing requirements for the new system.

Quality

The frequency of misdirected parcels as a result of sorting errors was not determined at this time. Therefore, reductions in this occurrence, while a viable area for quality improvement, is unmeasurable at this time.

4.4.8 The Warehouse Inventory Control System Operations

The Warehouse Inventory Control System (WICS) is an advanced man-machine system for material handling. Developed by Clay Bernard Systems International, WICS cost $12,000,000 to implement in 1975-76 and currently employs approximately 180 people. Approximately 200,000 storage locations occupy 320,000 square feet of building floor space. Primarily, avionics equipment and avionics repair parts are stored in the WICS warehouses which only receive material with maximum limits of 26 inches and 75 pounds.

WICS uses Remote Vehicle Processors, Remote Terminal Processors, and Central Controllers to assign bin and warehouse locations, guide the vehicles to the proper locations, maintain WICS inventory, and control all merchandise. This sophisticated automated equipment and the Data General Computer system are vital in accomplishing the three basic warehousing activities of receiving, storing, and issuing.

Receiving

Incoming merchandise is taken off of the base transporters and placed on temporary holding lines in the central receiving area. All merchandise is required to be accompanied by bar-coded paperwork to be processed through WICS. The merchandise is moved by a conveyor system from the central receiving temporary lines to a Remote Terminal Processor as space becomes available. The Remote Terminal Processor is a terminal used in the receiving area, hardwired to WICS, for accounting for all materials received. These terminals are also used in the issue area to finalize a shipment.

At the receipt terminal, the bar-coded document number is entered into the LOGMARS (Logistics Application of Automated Marking and Reading Symbols) system which was installed in June 1983. Data entry is accomplished by an operator manually passing a bar-code reading wand over the document. This data is processed by the WICS computer in real time and a bin location is promptly assigned for the item.

Locations are assigned on the basis of the size, weight, and quantity of a receipt. This warehouse and bin location, a WICS control number, the stock number, the quantity, the module number (staged for a particular zone: 0-9), and the zone number are printed on a Bin Routing Slip (BRS) at the receipt terminal. The WICS Control Number (WCN) is assigned to every receipt into WICS and every issue originated by WICS. It is used to record and control the assets in the avionics warehouse. The receipt terminal operator then manually sorts the merchandise into a designated tote (storage module) according to the bin routing slip information.

Storing

When a storage module is filled with receipts at the remote terminal, it is manually pushed to the appropriate zone where the Remote Vehicle Processor (RVP) will pick it up in order to store the merchandise. The RVP is the mobile portion of the WICS used to receive, issue, and process material for storage. The RVP is an electrically-powered, hydraulically-controlled vehicle with a lift section that will accommodate an operator, the control console, and a storage module for material. Each RVP is equipped with a processor which communicates with the central WICS computer, thereby controlling its movements and location in the warehouse. Routing and communications are obtained via wire, which is beneath the surface of the warehouse floor.

The RVP displays instructions for the operator upon reaching a bin location to direct the exact transaction to be performed. The Bin Routing Slip is also used in conjunction with the data and instructions displayed on the RVP for binning of materials. System interrogations may be initiated and received over any CRT during the binning of an item.

The WICS maintains total visibility of the item from the time it is entered at the receiving terminal, through the storing process, and until it is issued. When a receipt is binned by the RVP operator, a "task complete" button is pushed, and WICS is automatically updated. Other data processing systems which communicate with WICS (such as DO-33) are also automatically updated. DO-33 is a data processing system which manages data regarding local (basewide) issues.

Issuing

WICS issues consist of off-base issues (code 1348) and on-base issues (code Form 20). Off-base issue requests are entered into WICS via a magnetic tape that generated daily at the finance/accounting office. Local issues requests are entered directly from the DO33 system via hardware interface; the orders come in randomly throughout the day.

RVPs collect issue requests in a similar fashion as storing materials. The RVP automatically transports the vehicle operator to the proper warehouse location and displays the necessary information for the operator to select the binned materials. When the proper quantity is manually retrieved from the bin, the operator notifies the computer that the task is complete. An Issue Routing Slip (IRS) is then printed in the vehicle, for attachment to the order. The IRS has a WICS control number printed on its face that is used to control the item as it travels through the system. The merchandise with the IRS is subsequently placed by the operator onto a conveyor which transports it to the issue terminal area.

By examining the IRS, the issue terminal operator determines the correct method of handling the material and manually sorts the merchandise accordingly. Exception issues are sent to a special holding line in the issue area. The terminal operator must also check each issue to see if they are complete. If the issue is complete and the operator has identified it as an off-base issue, the shipping document is printed at the issue terminal. The completed off-base issues are sorted according to priority into appropriate holding lines to await transportation to the central shipping area in building 376. If the issue is complete and it is a local issue, the terminal operator must route it to the local issue terminal. There the shipping document is printed and the issues are manually placed into temporary bins until delivered to their respective base destinations.

If the issue is incomplete because all units of the issue are not received at the terminal at the same time, the terminal operator sends them to the local issue terminal, although the issue may be off-base. The local issue operator manually places the partially complete issue into a temporary storage location. When all units have been received, the shipping document is printed and the completed issue is sent to the correct holding line. These completed off-base issues are accumulated on specifically designated lines in the WICS shipping/receiving area where they are picked up periodically, and transported to building 376.

Observations

The manual task in WICS that is amenable to automation is that of sortation. Sortation basically incorporates acquiring a single package from those awaiting processing, orienting the item so the necessary information is within the field of view, and diverting the material to another destination.

Although sortation is not an obvious process to isolate, close inspection yields that it is the essential manual task that occurs throughout the operations in WICS. Reducing the need for an operator to physically handle the packages by eliminating the manual grasping, orienting, and diverting of the items has excellent long range potential to increase system throughput and general efficiency. While requiring substantial research effort, the sorting process is an excellent candidate for future automation as the manipulative elements are based on information that is readily computerized.

As discussed previously, after the receipts are entered into WICS by a laser scan, the receipts are manually sorted to their respective modules by the receipt terminal operator. When issues arrive at the issue terminal area, the operator must determine the correct handling route for the issue by visually checking each IRS and manually sorting the item accordingly, often multiple times. For instance, an off-base issue is sorted once according to completeness. If it is complete, the item is sorted again based on the issue's priority. If the issue is not complete, it is sorted a second time from local issues by another operator and ultimately sorted on priority by hand a third time to the temporary holding lines. At both of these Remote

Terminal Processor areas, merchandise becomes stagnant while waiting to be processed and sorted.

Another WICS task that is related to the sortation process is that of automated bin-picking. This concept was not pursued extensively as a primary application for several reasons. WICS accommodates a great variety of merchandise. Storage items are received daily that have never previously been introduced to WICS. This constant variability of material is compounded by the diversity of the item size and of the quantity requested.

A typical issue request (for instance: ten transistors) would necessitate pulling open a drawer location, identifying the correct compartment in the pull box in the bin, and retrieving the items one at a time. The retrieval process is complicated by the need for opening boxes, detecting overlapping or entangled parts, and gripping the items at specified locations to avoid damage. The refined gripper dexterity and vision technologies required to successfully execute such a bin-picking maneuver are at present unavailable or cost prohibitive. However, research efforts focusing on a less stringent sortation processes would advance the state-of-the-art and bring some capability of automated bin-picking into realization.

4.4.9 Conclusions for Sortation in the Air Freight Terminal

The application under consideration would obviously not be cost effective in itself. It represents a good site to be used as a "laboratory" to test prototype hardware and software emerging from research efforts to address the sortation problem. Accomplishments made during this first step would likely lead to cost effective applications in other more labor intensive sorting tasks in distribution operations.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The distribution operations at Warner Robins AFB are extremely complex by virtue of the size and number of facilities, the high transaction rates, and the extreme variability of the materials processed. Nonetheless, it is possible to categorize the operations and tasks according to the mission goals, the operations performed on items to achieve those goals, and the functional requirements required to accomplish a task or operation.

The efforts of the research team were focused on breaking down the operations performed on items into sufficient task detail to allow for the evaluation of functional requirements as pertaining to available and future robotics technology capabilities. This effort provided two significant results. It allowed for the identification of two cost effective applications that would meet the several criteria for implementation into the distribution complex. It further allowed for an assessment of the level of occurrence of the labor intensive operations throughout the process. That assessment provides for the long range planning aspects of robotics implementation that are in the best interests of the distribution mission.

The conclusions drawn from this study are three-fold:

1. Suitable cost effective applications for robot technology exist in the distribution process.

2. Additional applications can be achieved with moderate development efforts that will allow for expanded use of robotics technology.

3. Sorting is the fundamental task that is the most labor intensive and has the highest level of occurrence in the distribution complex. Research expenditures in this area will provide for many cost effective applications in the long term.

While the current capabilities of commercially available robotics systems are inadequate to perform the sortation task at the level of complexity found in the distribution process, a long range, focused research effort to provide those capabilities is in the best interests of the Distribution Directorate.

Recommendation 1

• Begin a program for implementing a robot system for gyro packaging.

The feasibility study for the gyro packaging task determines that the proposed system would be cost effective with commercially available hardware and minimal development effort. It is also a significant application to be considered for the first implementation of a robotics system in the distribution operations. It has been stated repetitively in management reports that the first implementation should be made on the basis of low risk, ease of installation, and sound cost effectiveness. This application meets those several criteria. It further allows for consideration of improvements in packaging quality through the use of packaging techniques which might otherwise be objectionable to human workers from an environmental standpoint. It also allows for the demonstration of a flexible packaging system which may be utilized at other Air Logistics Centers and can lead to further automation of other packaging tasks which might require moderate technical development. This is significant because the packaging operations in the distribution process exhibit a high level of occurrence throughout the complex.

We recommend that a program for implementation of the gyro packaging robotics system be undertaken immediately. Additional data analysis and engineering effort will need to be expended to detail a final system design. An equal effort will need to be expended on planning for those aspects important to successful implementation as mentioned in this report. Particularly significant in this regard are the participation of distribution personnel in the planning stages for the system and a thorough and detailed training program.

Recommendation 2

• Begin a program to detail system specifications for TAALS automation and to develop the required new prototype hardware.

The feasibility study for the TAALS automation concludes that this application is cost effective with the proposed system configuration. The implementation of a robotics system for this task holds one significant developmental milestone that will maximize the utilization of robotics systems in the future, that of integration with planning and control data processing systems. There is a historical trend towards increased computerized information processing for planning and control in distribution operations. Interaction with these systems is a fundamental requirement for advanced materials handling systems in the future. Implementation of the proposed system in TAALS allows for the development of capabilities to achieve this integration.

The second item of significance for this application relates to the capabilities to acquire and handle paperwork. The task of handling hard copy documentation accompanies most other tasks throughout the processing of materials in distribution operations. Implementation of this system allows for development of two capabilities in this regard. The first is a restructuring of the information acquisition and movement to reduce the level of paperwork handling. The second is the development of the system to handle a flexible material, the shipping label, which has similar characteristics to the handling of paperwork. Knowledge gained in the development of this capability will form a basis for consideration of further automation in regard to document handling.

Our recommendation is to plan for implementation of this system after the installation of the AWS information system at Warner Robins AFB. The engineering efforts required to further define and detail the system specifications, equipment designs, and capabilities development can be undertaken immediately. In particular, research efforts for the development of the automated labeling unit could be undertaken with minimal delay as this unit will require the longest duration of planning and development for this system.

Recommendation 3

- Begin a long range focused research effort to be conducted at Warner Robins Distribution Directorate and Georgia Institute of Technology to address the sortation problem.

The feasibility study for the air freight automated sorting application does not conclude a cost effective system concept. This, however, should not prevent consideration for utilizing this application as a starting point for a long range focused research effort to address the problems associated with the sortation task. As previously stated, sorting is the work element which occurs most frequently and demands the highest quantity of manual touch labor throughout the distribution operations. The trend of research and development efforts in the field of robotics technology is toward providing capabilities to achieve a level of flexibility that would be required for these complex problems. The attainment of capabilities to address the sorting tasks holds the greatest long run potential for cost effective automation in the Distribution Directorate.

The major problem posed by the sorting tasks are the extreme variability of items to be handled. The flexibility of the robotics system must be stretched to become a truly adaptive system in order to alter its processing cycle for each discrete item. This will require developments for advanced vision and ranging systems, highly flexible end-of-arm tooling, and highly efficient software to reduce the order of magnitude of data processing requirements. The development of a multi-facial bar code reading system, while optional, could also reduce the complexity of the task's functional requirements.

Our recommendation is for the Air Force to initiate immediate plans a long term research effort to address the complex sorting problem as applied to distribution tasks. It is envisioned that this research effort would be structured into building-block modules, each of which would extend the capabilities of a basic sorting system. It is further envisioned that research and development efforts for the initial installation would require approximately 11 man-years of research professional effort and 30 months duration. These estimates would be further refined in the planning stages for the research agenda. The application in the air freight terminal presents a structured and contained environment to reduce the risk of the development efforts and enhance the achievement of the goals of systems capabilities. Benefits from this effort would be applied to cost effective sorting applications in other distribution operations.

APPENDIX A

HUMAN FACTORS CONSIDERATIONS

HUMAN FACTORS CONSIDERATIONS

As one of the most important industrial developments for the 1980's, the introduction of robot technology has become the subject of discussion among industrial managers and labor officials. The changeover to new technology will not likely occur without lasting effects on human resources. As is sometimes feared, the human element will not be eliminated with the intervention of robots. Instead, it is here to stay, at least for the time being (during the transition). Planning then for implementation of new technologies must include the transitional stages of human resources. It is these transitions that are of major concern to management and labor representatives.

Traditionally, labor has been wary of management's attempts to improve productivity. Resistance has resulted for reasons such as poor administration of previous programs and well developed organizational cultures of adversary relationships between management and labor. Robots pose a threat of increased productivity, implying a notion of "more work performed by fewer workers." It is not surprising that labor officials are keeping watch over technological developments and how the introduction of these into their prospective work places will affect the numbers of the work force. Will current employees lose their jobs to robots? Will current employees lose their jobs to more skilled personnel? How will the hiring rate of employees in the future be affected? Management must be prepared to effectively answer these questions. Already labor contracts exist which include provisions that specifically spell out the process to be followed at the introduction of new technology. Successful or not, these are negotiated and agreed upon by both parties. It is likely that, as increasing applications of new technology become apparent, similar agreements will be made by the remaining management-labor entities to ensure acceptance by both parties.

With the introduction of any new industrial activity, both management and labor may exhibit resistance to change. Negative attitudes are exhibited by remarks such as, "Why bother?" and "We've done it this way for thirty years, why change now?" The underlying attitudes for these remarks are difficult to overcome. Since they are organizationally specific, standard packages for attitude improvement are not helpful. Successful introduction of new technology, following through to implementation, must be organizationally specific and tailored as such.

The best approach by management is to isolate an operation adaptable to new technology and work out an acceptable transition, designating this as a pilot program. Care must be taken that this pilot does not fail in gaining worker acceptance. It must be fool-proof in the sense that, whether successful or not, the project is not rejected by the parties involved. To achieve this, labor should be consulted early in the planning stages. Participation throughout the project will warrant acceptance by the membership later. The purpose of involvement is to bring about ownership. In this respect, even failure will arouse involvement and encourage further commitment when identifying what went wrong.

Job displacement is inevitable with the introduction of new technology. When examining a recommended change in numbers or structure of the work force, the only satisfactory remedy to the labor side is a steady or increased rate of employment. Reduction in force is not an acceptable alternative. If a reduction is inevitable in the work area undergoing technological transition, the only acceptable solution is that workers be absorbed elsewhere in the organization. Any additional reduction in force should be done by attrition.

The reassignment process can take many forms. Displaced workers can be placed elsewhere to perform similar tasks or can be assigned more challenging tasks. Reassignment to more challenging tasks involves retraining. Retraining can take place in-house or out-of-house depending on the organization's facilities and needs. Assignment to some new jobs may be simple, requiring limited on-the-job training. But extensive retraining may be required when assignments are to higher skilled jobs such as operation of the new system. This is where early planning with labor is a plus. Concurrent retraining and project planning deters hiring from outside, and again, instills ownership through participation. In the long run, concurrent training can serve to elevate job satisfaction as well as alleviate the threat of lost jobs.

Perhaps a difficult task to undertake is the selection of trainees. Guidelines of labor contracts may have to be followed in carrying out the internal selection process. While it is easier to gain initial acceptance by selecting from within, additional personnel may need to be selected from outside when the internal labor pool does not consist of adequate qualifying personnel to meet technical training needs. External selection can be for in-house training candidates or for already trained technicians. Again, the nature of the selection process depends on the selecting organization's facilities and needs.

The availability of already-trained technicians is increasing with the growing number of technical institutions that are offering technician degrees in the applications of robotics. Robotics training has even begun at the high school level. These highly structured programs are materializing particularly in heavily industrialized areas, such as automobile-producing centers, assisting industry in the training of youth for future employment as well as currently laid-off personnel. Modern technicians will have to work on all systems--electrical, hydraulic, pneumatic--that operate robots. Training is needed to familiarize them with programming, computers, microprocessors, programmable controllers, grippers, vision systems, and many more.

Retraining does not stop with the workers. The retraining of managers must be undertaken as well. Reward systems of supervisors and upper management must be brought in line with responsibilities of new operations. Much like instilled ownership through participation in the labor ranks, acceptance at upper levels filters down through the managerial ranks establishing an organizational climate conducive to innovation.

With the addition of new job titles and responsibilities, amendments to standard classifications for job performance will need to be made. All employees will be given a wider range of responsibilities. In essence, responsibility will lie with the whole system, not just one aspect. In this respect new technology will not take jobs away; rather it will increase scope of work, responsibility, and finally, increase job satisfaction. The addition of robots will merely be the addition of tools for the sole purpose of complementing human competencies.

In summary, the introduction of new technology--in this instance, robotics technology--requires a joint management-labor effort to insure successful planning, implementation, and success. New technology sheds light on the futures of workers and their families. Training of younger people in robotics will help them acquire jobs in needed areas. Robots will perform menial work, leaving the challenging tasks to humans. In so doing, robotics technology will improve the quality of work life in the organization.

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APPENDIX B

SENSORS FOR ROBOTIC SYSTEMS

SENSORS FOR ROBOTIC SYSTEMS

Switches

Electrical switches are probably the most basic form of sensors used in robotic systems. They provide binary output for the on/off status of other devices and operations.

Rheostats

Rheostats are variable forms of the basic switch and can be electrical or fluidic. They provide analog information related to the rate status of other devices and operations.

Proximity Sensors

Proximity sensors detect when one object (usually an end effector) is close to another object. Close can be anywhere from a few inches to a millimeter, depending upon the device used. These devices primarily indicate only the presence or absence of an object within their sensing region, but some can also give information about the distance between the object and the sensor.

Eddy-current proximity detectors produce an alternating magnetic field in a small volume of space such as at the tip of a probe. This field induces eddy currents in any conductive body that enters the sensitive volume. The eddy currents produce their own magnetic field that opposes the field emitted by the sensor. Coils or solid state magnetic field devices detect any change in the flux density and signal the presence of an object. The sensitive volume is usually quite small so that eddy-current proximity detectors are appropriate for detecting the presence of objects when they approach only to within about one millimeter.

Magnetic-field devices are very useful proximity detectors. These sensors may be constructed with a reed switch and a permanent magnet (in the object to be detected). Alternatively, the magnet may be part of the sensor, and the presence of the object can complete a magnetic circuit that operates the reed switch. The combination of a reed switch and a permanent magnet is appealing because neither device must be supplied with power for operation. Other forms of magnetic field sensors, such as Hall-effect devices and magnetoresistive elements (usually integrated with a solid state amplifier for increased signal output), may also be used.

Proximity detectors can operate on the basis of electrostatic effects. The difficulty with these detectors is that they are quite sensitive to stray fields radiated by electrical equipment and to static charges induced by friction or spraying operations.

The touch-sensitive button, such as those used in modern elevators, can also be adapted for use as a proximity detector. In some of these devices, the capacitance between a person's body and the respective surroundings changes the resonant frequency of a tuned circuit. Usually, these devices only react to contact with a large conductive object, such as a person. However, by attaching a conductive plate or rod to the contact point, the device can respond to objects at a distance by virtue of their self-capacity.

Fluidic proximity detectors usually operate on the back pressure created when the presence of an object blocks an exit orifice. These devices can provide rather precise indications of extremely small clearances between the orifice and the object. These devices are routinely used as sensors in automatic noncontact gaging and inspection equipment.

Optical proximity sensors that are readily available operate on either visible or invisible (almost always infrared) light. Most measure the amount of light reflected from an object. A factor in their reliability is the type of light source that they use. The infrared-reflectance sensor with an incandescent light source is one of the most common. This sensor is widely available and inexpensive.

Most optical sensors require a source of light. Incandescent filaments operated at reduced voltages can have multiyear lifetimes, but are susceptible to damage from vibration. Light-emitting diodes have the reliability that is characteristic of other solid state devices; they are insensitive to shock and vibration and are preferred over incandescent light sources. Other sources, such as electroluminescence or radiation-induced fluorescence, are not commonly used. Laser diodes can emit milliwatts of coherent light, but at present they are extremely expensive and their reliability is not well established.

An acoustic proximity detector was recently developed, and consists of a cylindrical open-ended resonator cavity. An acoustic emitter at the closed end sets up standing waves within the cavity. The presence of an object at the open end of the resonator cavity changes the distribution of standing waves within the cavity. A microphone placed in the wall of the cavity detects the change in sound pressure as the standing-wave pattern moves. This device is also capable of precise measurement of the distance to the object.

Range Sensors

A range sensor is a device that can provide precise measurement of the distance from the sensor to an object. Such devices are useful for locating and tracking objects within the work-station area and for controlling a manipulator.

Two kinds of commercially available devices are effective over wide range measurements. These are tellurometers and laser interferometric gages. The former is inappropriate for industrial applications because distances measured are on the order of miles, to an accuracy of only about one foot. Interferometric devices can measure distances over the range of interest and have greater precision, but are extremely sensitive to environmental conditions such as humidity and temperature. In addition, these devices do not satisfactorily withstand rough handling or vibration. They are extremely expensive, and require skilled operators.

Basic optical range-sensing schemes include stereo, projector/camera, and laser-scanner/photomultiplier technologies. Sensing range with a stereo pair of TV cameras encounters the problem of determining corresponding points in the two images of the object. The main drawback of the laser-scanner/photomultiplier scheme is that it is too slow, especially if the target is dark. This drawback may be resolved by increasing the laser power, increasing the photomultiplier-receiver area, or improving other sensor parameters. Each of these solutions may, in turn, introduce new problems like safety, size, and cost.

Acoustic range devices operating on sonar principles are available. One problem with acoustic ranging devices is that their transverse spatial resolution is not very good because of the difficulty of producing a narrow beam of sound without elaborate equipment. Acoustic range-finders, like the one used in Polaroid cameras, yield only a single range value. To obtain a range image, they must be scanned and spurious echo signals must be disregarded. In addition, for high spatial resolution, new techniques are needed to overcome the absorption of the energy of a high frequency acoustic wave by its medium.

Tactile Sensors

Tactile sensors respond to contact forces between themselves and other objects. Unlike proximity detectors, tactile sensors do not indicate the presence of an object until it actually touches the sensor. A useful combination of sensors in an end effector is a proximity sensor that works in conjunction with a touch sensor. The proximity detector can detect the presence of an object at some distance so that the controller can safely move an end effector quickly towards that object even if its position is not precisely known. The signal from the proximity detector would give the controller advance warning to slow down and avoid a collision. The controller, monitoring the touch sensor, can achieve "soft" contact while moving the end effector slowly towards the target.

Tactile sensors can be classified into touch sensors and stress sensors. Touch sensors produce a binary output signal, depending upon whether or not they are in contact. Stress sensors produce signals that indicate the magnitude of the contact forces. Individual stress sensors usually respond only to forces in one direction. However, combinations of two or more can report forces, as well as torques, in two or three directions.

Microswitches are probably the least expensive and most commonly used form of touch sensor. Microswitches should be mounted so that they are protected against accidental collisions with objects in the workspace. These devices can be equipped with mechanically compliant feelers to protect against excessive force and to extend the region in which they can sense contact.

In one type of touch sensor, a jet of air flows from the top to the bottom gripper. When a part is picked up, the air flow is interrupted signaling the robot controller. If a part is not picked up, overgripping is detected by a microswitch. Another type of sensor uses pressure sensitive limit switches instead of an airjet.

Inexpensive tactile sensor arrays may be constructed from commercially available rubber sheets that have been doped with silver granules to provide conductive electrical properties. The resistance across the sheet is normally quite high, as rubber is an insulator. When an object touches the sheet and compresses it, the resistance across such a sheet decreases abruptly. At a certain level of compression, sufficient silver granules come into contact to form conducting pathways from one side of the rubber sheet to the other. Thus, electrical connections are formed through the sheet at each place where an object touches it.

Strain gages are often used to make force sensors, torque sensors, and sensors that can measure both kinds of stress simultaneously. The sensors are usually constructed by attaching individual strain gages to the roots of cantelever beams that are milled into solid blocks of aluminum. The orientations of the beams and the connections between them may be designed to mechanically resolve the applied force and torque into its six components with respect to a set of Cartesian axes fixed in the block. Alternatively, the beams may be positioned according to other criteria such as strength or convenience of manufacture.

The various stress components may also be resolved with appropriate software. Transforming a set of forces and torques form one reference frame to another with software or appropriate analog computer hardware is a simple matter called remote moment sensing.

Shimano at the Stanford Artificial Intelligence Laboratory has demonstrated an advanced software technique. Shimano, using eight strain gages, formed an eight-element vector from the signals they produced and multiplied that vector by a six-by-eight matrix of sensitivity coefficients. He also demonstrated an elegant method by which the controlling computer could work out the values for those coefficients rapidly and without using any special mechanical or electrical measuring equipment. In this procedure, the sensor is mounted between a manipulator and an end effector (such as a wrist). The procedure uses the end effector's known weight in a fully automatic calibration for a six-degree-of-freedom, stress-sensing device. The calibration procedure is carried out by the controller without human aid.

Commercially available tactile sensor systems include the Lord Corporation systems and the Barry Wright systems. The Lord Corp. devices perform continuous variable monitoring of forces which are pressing against a number of sensing sites in an elastomeric touch surface. The sites are mounted in the form of a matrix array and operate independently. Lord's LTS200 sensor is 1.75" long, 1.125" wide, and 0.65" thick. The rectangular array consists of 96 sensing sites on 0.10' centers. Each site is sensitive to forces as low as 0.050 lb. Loads up to 25 lbs. perpendicular to the touch surface can be handled by this small unit. Other arrays are to become available in the near future.

According to Lord, the sensor provides the ability to determine loads and moments relative to the place where touching actually occurs, as well as the pattern of touch. In effect, this places a miniaturized force/torque sensor directly underneath the touch surface and should add to the unit's versatility. In a robot gripper, the sensor can determine the orientation of an object, its location relative to the sensing pad, and its shape.

The Barry Wright TS402 system consists of a compliant touch sensor pad and an electronic interface device to connect the pad to the robot controller. The active area, which measures 1.56" x 1.56", contains a matrix array of 256 sensing points on 0.100" centers. Overall, the pad measures 2.50" x 2.60". It is 0.35" thick. The design incorporates conductive elastomers which make overloading unlikely and reduces the chance of damaging delicate objects during handling. The system provides data which can be used to determin force, position, and part orientation. It can also determine where an object is within the robot end effector and detect slippage.

Artificial Vision

Artificial vision systems have evolved for robotic use only in recent years. SRI has developed a prototype hardware/software system called the Vision Module for a variety of industrial computer-vision applications, such as in-process inspection, sensor-controlled manipulation and visual servoing. It is a stand-alone unit that can be used in two distinct ways: to recognize parts from their size and shape regardless of position or orientation, without reprogramming; and as a processor containing a general-purpose binary-vision subroutine. This is easily programmable to perform more complex visual tasks, including inspection and preceise dimensional measurements.

The Vision Module consists of three mahor components: a GE Module TN-2200 tv camera with 128 x 128 elements; a DEC LSI-11 microcomputer with 28k-word memory and an interface preprocessor between the TV camera and the microcomputer. Operation is based on binary angles, This technique is called 'run-length coding' and imposses rather stringent requirements on the scene to be imaged. A flash-lamp strobe is provided to obtain frozen images of moving objects. Processing times depend on two separate factors: the complexity of the image and the amount of visual processing that has been selected. The time required to read-in, process and implement recognition of the same image has been measured and found to be 1.4 seconds which should be reduced substantially in the near future.

General Motors has developed Consight, a vision-based robot system capable of picking up parts placed randomly on a moving conveyor belt. The vision system detemines the position and orientation of parts on the belt. The robot tracks the parts and transfers them to a predetermined location. The system can be easily retrained for a wide class of complex curved parts, providing that they are not touching one another. The maximum-speed limitation is imposed by neither the vision or the computer control, but by the cycle time of the robot arm.

Consight is logically partitioned into independent vision, robot and monitor sybsystems which can be interchanged easily, thus increasing flexibility. The vision system uses structured light in which two projected light lines, focused as one line on the belt, are displaced by objects on the belt. The line camera, focused on the line detects a silhouette of passing objects. When it has seen the entire object, the vision system sends to the monitor the object's position and a belt-position reference value. The robot system then executes a previously taught program to transfer the part from the conveyor to a fixed position.

The vision system employs a linear-array camera having 256 discrete diodes of which 128 are used. Uniform spacing between sample points is achieved by using the belt-position detector. The system does not require a high-contrast scene. Shadowing effects are overcome by using more than one light source. External boundaries will be sharp, but some internal features, such as holes, are subject to distortion or occlusion due to the over-shadowing effect. The system operates at a cycle time of 5 seconds and at belt speeds of up to 20 cm/sec.

The National Bureau of Standards' robot vision system consists of a solid-state camera, a strobographic light source, and an 8-bit microprocessor. The camera is mounted obliquely at the wrist of the robot. The light source flashes a plane of light parallel to the wrist of the robot into this region. The plane of light strikes any object in this region and produces an image of line segments. The system computes a run length coding representation of line segments.

As the hand, and consequently the camera, moves closer to the box, the line segment formed by the reflected light in the image formed by the reflected light in the image moves further down and becomes longer. The resolution also becomes finer as the hand moves closer. This type of non-uniform resolution is very desirable for robot vision. In part acquisition, the coarse resolution at large distances can be used to adjust trajectories to move in close enough to obtain more precise data in the fine resolution part of the scale. The fine resolution allows more precise inspection operation such as dimensional measurements. The shape of the line segment patterns also gives information about the structure of the object.

The flash duration is under computer control which enables the vision system to optimize picture quality by adjusting the flash until the reflected line exceeds the threshold by a satisfactory amount.

Brown Boveri has produced a versatile optoelectronic sensor for industrial robot systems. The range of applications is recognition and measuring position of working pieces, visual inspection, object tracking and robot control by optical feedback. The optoelectronic sensor, which is programmed by a 'teach-in' process, is self calibrating and the relationship between the co-ordinate systems of the sensor and the robot are also defined by a 'teach-in' process. The system allows the adaption of four TV cameras to process different images in a multiplexed manner.

In a typical application, the sensor recognizes the objects and measures their position and rotation angle. The robot picks up the pieces from the moving conveyor after they have left the field of view. The sensor is able to track simultaneously up to ten objects between the field of view and the pick-up point. Proper functioning of the system can only be achieved if the coordinate systems of the sensor and the robot are adjusted to one another.

Work pieces must provide good contrast to the background and the camera has to be in a defined, fixed position relative to the object scene. Objects must reach the field of view isolated from each other, not touching or overlapping and only rigid objects may be processed. They must only have a limited number of stable positions on a plane and be definable by two-dimensional patterns. The total processing speed is 32-200 ms.

Limited three-dimensional technology that is capable of accurately determining depth is now available. Using structured light and optical triangulation techniques, these vision systems are able to map complex contoured surfaces and provide a 3-D coordinate number for each surface point. Such 3-D systems are independent of variations in light intensity or shades of gray on an object's surface. They produce direct, unambiguous measurements of the X, Y, and Z positions relative to the robot coordinate system.

Bin Vision(TM) by General Electric pinpoints part location and orientation. This vision systems enables a robot to locate and acquire randomly oriented, overlapping parts from a bin, conveyor or other work area. This system can accommodate up to four cameras and thus work with four parts simultaneously at a typical cycle time of five to 20 seconds, including image processing and robot transfer. Product sizes and shapes can vary within certain limits, but the parts must be opaque, relatively rigid, under 17 pounds in weight and reflective.

The DataMan vision system by Cognex Corp. automatically reads codes (letters, numbers, and symbols) which are printed, etched, stamped, or inscribed directly on product surfaces, including cardboard. This information is then relayed to a robot or other material-handling equipment for routing and tracking. The system can read laser-etched information the size of a pinhead on polished or matte-surfaced semiconductor wafers at a rate of 15 characters per second, or misaligned coding on twisted aircraft wires.

Recently introduced by Westinghouse Electric Corp., the GVS-41 vision system can distinguish 64 shades of gray and process up to 10 images per second under normally available light. It is described as offering dramatic improvement over the silhouette recognition methods used by conventional binary vision system. Up to 10 cameras can be used for complex sensing applications.

APPENDIX C

GRIPPER TYPES AND DESIGNS

GRIPPER TYPES AND DESIGNS

Grippers are used primarily for two distinctly different purposes: for performing pick-and-place operations and for holding tools to perform processes on workpieces. Tools are used for specialized jobs such as welding, painting, or driving screws, while pick-and-place grippers perform more generalized tasks of materials handling.

Grippers are usually specially designed to the task. Material handling grippers may include vacuum or adhesives, magnetic devices for ferrous materials, and mechanical devices. Mechanical configurations include shovel designs, simple open-and-close pincers, complicated cam-actuators, and many other forms. Other grippers are moldable, inflatable, or possess soft fingers.

Friction and Physical Constraint Grippers

Friction and constraining grippers are usually linkages or jointed mechanisms, operated by one or more actuators, some of which may be servoed. These grippers may also be constructed with inflatable bladders in various configurations to grip parts of particular shapes.

Friction grippers exert pressure on an item, either by expanding within it or by closing on it externally. Friction grippers generally rely on soft materials at the point of contact with an object in order to provide sufficient frictional force for a secure grasp. Material that will remain soft under repeated loading and that is oil-resistant, if the manipulator is hydraulically-powered, should be chosen.

Physically constraining grippers may or may not exert pressure on an item. Instead, these grippers grasp the workpiece by placing solid material around or under it. Most of these grippers hold an object rigidly, but in one design, suitable for light-duty use, prehensile elastomeric fingers curl gently around the item when high pressure air is pumped into them.

Linkage designs used in grippers can be identified as being either parallel-jaw, two-fingered, three-fingered, or multi-fingered. Parallel-jaw gippers contact the item over relatively large areas by contacting flat sufaces on opposing sides, Finger grippers usually make contact at relatively small regions.

There exists a wide variety of mechanical linkage type grippers which have been designed to meet different robot applications. The standard hand is an inexpensive, all-purpose unit that will accept many different fingers. Fingers are generally tailored to the parts to be manipulated. Simple linkages provide both the finger action and the force multiplication needed to grip the object. At the completion of finger closure, the fingers exert their maximum clamping force on the part.

Fingers using self-aligning pads are valuable for assuring a secure grip on a flat-sided part. 'Cocking' of the part is unlikely when these pads are employed. A particlar finger design need not be restricted to individual sized items. The fingers can be constructed with several cavities for parts of different sizes and shapes. The robot is pre-programmed to position the hand so that the proper cavity will match the location of the part.

Heavy weights or bulky objects are handled easily by a cam-operated hand. More expensive than the standard hand, the cam-operated hand is designed to hold the part so that its center of gravity is kept very close to the wrist of the hand. The short distance between the center of gravity and wrist minimizes the twisting tendency of a heavy or bulky object. To achieve this close coupling of hand and part, there is a sacrifice: a specific cam-operated hand design will accommodate only a very narrow range of object sizes.

A special hand with one movable jaw is another gripper type. A hand with a single-acting jaw should be considered when there is access space underneath an object. Where this hand can be applied, it will scoop up an object quite quickly. Simplicity of the design makes this one of the most economical hands. A dual-jaw hand will open wide to grasp inexactly located objects of light weight. Lifting and placement of boxes and cartons is an appropriate application. Actuators and jaws can be re-mounted in any of several positions on the fixed back plate, making it practical for the same dual-jaw hand to move different size cartons.

Pneumatic actuators are use in many special hand designs for robots. Lifting capacity is dependent upon friction developed by the fingers, but heavy parts can be handled it the fingers can secure a more positive contact such as under a flange or lip.

Secure grasping of relatively short tubes is the forte of the next mechanical gripper. Pick-up is effective even when tube length varies. The fingers of the hand close in two stages. First, they travel through an arc until they are vertical; second, the acuator draws them together axially. Linear travel in this second stage of closure is selected to accommodate the range of tube lengths to be handled.

The Skinner hand is a versatile gripper. Frank Skinner suggested a three-fingered design in which each finger is capable of prehension, and a joint at the base of each allows it to twist about its long axis. This kind of hand can be used for friction and physical constraint modes of gripping.

Attraction Grippers

Attraction grippers typically use magnetic force or suction to hold an object. Adhesion has not been readily used to date. Arrays of magnets or suction cups on compliant mountings are useful in grasping irregularly shaped items. The standard practice to reduce the air-flow rate required to operate a large array of suction cups is to place a valve in each cup. The valve connects that cup to the vacuum line when the cup contacts an object. Placing an orifice between each cup and the line is a less effective but cheaper solution to the same problem.

Vacuum cups are normally made of an elastic material that conforms and forms a seal to the surface of the part to be handled. If the part is elastic, then the cup can be made of a hard material. There are other configurations that differ in principle. Some cups, or vacuum pads, are made of cellular material through which the air is drawn. They have the advantage of being suitable for rough and porous surfaces because each cell constitutes its own little vacuum cup. If one fails to make a seal, it is paired up with neighboring cells and they together form a larger cup. The life of vacuum cups is quite good, especially in relationship to their price. Polyurethane cups seem to have a longer life than those made from natural or synthetic rubber. Vacuum cups are catalog items and there is a selection to choose from in both configurations and sizes. The number of cups to be used in a design depends on such factors as: weight of the load, size of cups available, location of the center of gravity and the support needed to handle large flimsy parts.

The vacuum cup pick-up has many of the virtues of a magnetic pick-up and is much less susceptible to side slippage of the item. For light to moderate weight items, the vacuum pick-up is an excellent choice and fragile items are handled easily. The vacuum pick-up has better reliability than the magnetic pick-up.

APPENDIX D

RESEARCH TOPICS FOR FUTURE ROBOTIC CAPABILITIES

RESEARCH TOPICS FOR FUTURE ROBOTIC CAPABILITIES

Developments in Tactile Sensors

Carbon fibers may be used to provide a wide range of tactile and force feedback information. Carbon fiber tactile sensors make use of the resistance change between individual carbon fibers under pressure. Because of the strength of the material, the sensors endure high temperatures and loads. A highly flexible material, carbon fibers may be tailored to any shape of manipulator. Carbon fiber tactile sensors for robotics use were explored at the University of Warwick under research sponsored by the Science Research Council. Researchers at Georgia Institute of Technology are working toward the development of new forms of sensors using carbon fibers.

Scientists at MIT and in France are working on developing touch sensors in artificial skins, opening up the possibility of having a robot determine orientation and identity of items by touch alone. At MIT, a skin of silicone rubber is used. The rubber yields when the finger closes on an object, permitting a fingertip-sized sensor to activate. The sensor, which contains 256 tiny pressure-sensitive switches arranged in a 16 x 16 grid, can discriminate between screws, cotter pins, and washers.

A project at Carnegie-Mellon University involves development of a prototype tactile sensor array. The prototype device is based on a polymer film, polyvinylidene fluoride, which is sensitized by mechanical, thermal, and electrical treatment to give it piezoelectric properites. After sensitizing, the film is metalized on both sides for electrical contact. Mechanical protection for the delicate metal layer is provided by a rugged insulating overlay. According to the facility director, the prototype device has 16 discrete sensor pads arranged in a 4 x 4 array which are mounted on a square of copper-clad Fiberglas circuit board. Each element is overlaid with a small square pad of unclad circuit board material. The array is supported on one face of a rigid rectangular prism with the preprocessing electronics located inside. A flexible, multiwire cable leads from this package to the remaining electronics. Thus, the sensor array can be moved freely by the manipulator without degrading the signal quality.

At Georgia Institute of Technology, one project that is sponsored by the Materials Handling Research Center is focused on the integration of tactile and vision sensors to address the problems of overlapping item recognition. Another project aims to refine the physical characteristics required of tactile sensors used for particular tasks.

At MIT, the Artificial Intelligence Laboratory has a project on touch and force-sensing systems employing conductive silicone ruber. Two electrodes are arranged so that when pressure is applied to the assembly, the two are forced together. One, or both, of the electrodes is made of electrically conductive silicone rubber. One, or both, has a convex shape. One of the components could be made of metal, which would be forced into the surface of a block of silicone rubber. With the device in its unstressed state, the area of contact between the two electrodes is minimal. If a voltage is applied between them, all conductive paths converge on the point of contact, and resistance is high. When pressure is applied, the rubber is deformed by the rigid electrode and the area of contact increases. This allows more current to flow, and resistance decreases rapidly. A prototype has a 16 x 16 matrix using discrete rubber cords. In actual use, sensors of this type would be covered by a compliant "skin," to which the top electrode would be attached, while the lower electrode would be fixed to a rigid surface. There are some possibilities for a system where the entire sensor could flex.

Developments in End Effectors

The Japanese have pioneered in the design of tentacle-like mechanical linkages that wrap themselves around the material and conform to its shape. An unusual kind of gripper for objects of unpredeictable shape can be made with a granular material, such as sand or magnetic particles, in a loose bag. Draping the bag over an object and applying a vacuum or magnetic field gives the powder sufficient rigidity to support the object when the bag is lifted. A magnetic fluid could also be used. Fluidized beds of sand or ball bearings can be used as vises or clamps with vacuum or magnetism as an aid in rigidifying the medium.

Developments in Artificial Vision

Most experts agree that robots will be unable to reach their full potential as industrial workhorses until they are better able to monitor their environment and react to changing conditions. Many robotics specialists feel artificial vision will be the primary tool to accomplish this adaptation.

Artificial vision is very much in its infancy, but already specific goals have been identified which are important to the future of robot technology. Challenges that robotics engineers are currently undertaking include three-dimensional (3-D) technology which would allow robots to know more about objects they are viewing, and visual bin picking, which consists of identifying randomly oriented parts and sorting them.

One of the major problems to be overcome before a practical bin picking system is achieved is that posed by overlapping parts. Present technology allows a vision system to identify a part that it has previously been taught to recognize, provided that the part is not lying on top of, under, or touching another part. Touching parts are a regular occurrence in the bin picking task.

In approaching this problem, one robotics company, Adept Technology Incorporated, has developed a system that looks at a blob (the term used to describe an object viewed by the system), analyzes the object's boundary and shape features (lines, arcs, corners, and holes), and classifies the objects by comparing them to those it has been taught to recognize. Partial observation of a part may allow sufficient features to accomplish the recognition.

The system relies heavily on advanced algorithms designed to make the recognition process as fast as possible. Adept Technology's vision system with its advanced algorithms can recognize overlying parts at the rate of two per second.

Further advances in artificial vision system hardware, algorithms, illumination techniques, and 3-D imaging will allow robots to be more adaptable in unstructured, changing work environments.

Developments in Artificial Intelligence

There is a current revival of interest in Artificial Intelligence (AI), renamed Expert Systems for the '80s. A popular topic in the '50s and '60s, AI was an attempt to make machines perform tasks that were considered to require human intelligence. Proposed accomplishments centered around the development of problem-solving algorithms in search of optimal solutions. A classic example was the AI proponents' declaration to make a machine the chess champion of the world. Since this and similar predictions did not materialize, serious doubt was cast on AI as a practical technology. Adding further more serious gloom was the fact that the algorithms produced solution spaces too large to be handled by current or future comptuer systems. Consequently, funding by government agencies and industry declined drastically by the '70s.

Today's field of Expert Systems concentrates on writing programs that incorporate solution space encompassing only "rules of thumb." The justification for not exhausting all possible alternatives is that Expert Systems are designed to simulate the intuitive process of expert human decision makers. Humans don't exhaust all alternatives when problem-solving so why should Expert Systems? If effectively operating as a human system, workable solutions, whether optimal or not, are readily accepted.

There are existing Expert Systems operating in industry today. Participants in this field are anticipating increased demand for these systems in the '80s. But increased demand is based on increased acceptance as technological advances warrant.

Expert Systems in robotics is one application to be seriously contemplated. Computers today are sufficiently sophisticated such that techniques used to program intelligent behavior have become more realistic. Further, the growing acceptance of computers and robots for industrial use indicates industrial readiness to recognize the new technology.

Expert Systems can relieve the robotics expert in time-consuming activities including the search for robot arm solution, the design of the robot workplace, and the diagnosis of robot malfunctions. In each instance, the user is prompted for identification of parameters, constraints, and tradeoffs. The program then works this data into a data base using rules for transforming the data base and a control strategy for selecting applicable rules. Timely decisions are then made based upon the expert knowledge that is the basis for the program.

In the future, Expert Systems may assist the robot itself to make changes in its program cycles to adapt to changes in activities or items within its work cell, thereby eliminating the requirement for complete reprogramming.

APPENDIX E

STATISTICAL DATA FOR GYRO PACKING

GYRO DATA ANALYSIS

AS PACKED WEIGHT:

Maximum:	50 pounds
Minimum:	2 pounds
Average:	20.7 pounds

LENGTH:

Maximum:	13.312 inches
Minimum:	3.000 inches

WIDTH:

Maximum:	12.500 inches
Minimum:	1.500 inches

HEIGHT:

Maximum:	11.000 inches
Minimum:	1.500 inches

Average length, width, and height were not calculated because of the large amount of missing information.

RAW GYRO DATA
Annual Quantity and Individual
Gyro Weight as Packed

RECORD #	GYRO STOCK #	QUANTITY	LB/GYRO
1	1270004767945	147	20
2	1270007097670	132	13
3	1270009091639	61	13
4	1270009173188	24	35
5	1270010031763	53	28
6	1270010469884	62	18
7	1280006076006	391	39
8	5826001345977	728	31
9	5826001345981	1344	31
10	5826005034939	8	7
11	5826005052219	19	9
12	5826005052221	17	9
13	5826005052222	117	7
14	5826005053092	35	9
15	5826005053094	987	7
16	5826005053096	156	9
17	5826005053140	995	9
18	5826005575818	517	9
19	5826006289710	17	5
20	5826009049822	341	9
21	5826010140028	141	31
22	5826010659189	23	31
23	5841008454243	671	22
24	6615001376038	159	4
25	6615001691564	93	5
26	6615003483842	396	12
27	6615004479683	1812	28
28	6615005156000	654	18
29	6615005156011	119	12
30	6615005156032	300	12
31	6615005279281	1147	50
32	6615006206926CW	1	10
33	6615006638696	552	11
34	6615007635231	708	5
35	6615007784077CW	1	10
36	6615008096825CW	34	10
37	6615008570828	1239	2
38	6615008690825	489	2
39	6615009006853	301	27
40	6615009034414	361	27
41	6615009336037	1589	27
42	6615009585310	2	4
43	6615009732218	1926	27
44	6615010182177	14	0*
45	6615010597909	7	4

*Weight Data Not Available.

RAW GYRO DATA
Physical Dimensions

RECORD #	GYRO STOCK #	LENGTH (IN.)	WIDTH (IN.)	HEIGHT (IN.)
1	1270004767945	---*	---	---
2	1270007097670	---	---	---
3	1270009091639	---	---	---
4	1270009173188	---	---	---
5	1270010031763	---	---	---
6	1270010469884	---	---	---
7	1280006076006	---	---	---
8	5826001345977	---	---	---
9	5826001345981	11.110	5.000	4.250
10	5826005034939	3.000/6.000	---	---
11	5826005052219	---	---	---
12	5826005052221	7.188	3.250	3.250
13	5826005052222	---	---	---
14	5826005053092	3.250	3.250	7.188
15	5826005053094	3.250	3.500	6.156
16	5826005053096	3.250	3.250	7.188
17	5826005053140	6.250	3.250	3.250
18	5826005575818	3.25	7.810	3.25
19	5826006289710	---	---	---
20	5826009049822	---	---	---
21	5826010140028	8.750	5.000	4.250
22	5826010659189	---	---	---
23	5841008454243	---	---	---
24	6615001376038	5.195	2.890	2.872
25	6615001691564	---	---	---
26	6615003483842	9.375	8.000	6.921
27	6615004479683	---	---	---
28	6615005156000	8.220	7.220	6.28
29	6615005156011	9.531	8.000	6.609
30	6615005156032	9.531	8.000	6.609
31	6615005279281	13.312	12.500	11.000
32	6615006206926CW	3.172	3.172	3.000
33	6615006638696	7.625	6.437	8.015
34	6615007635231	5.375	2.812	2.156
35	6615007784077CW	3.800	3.172	3.172
36	6615008096825CW	3.172	3.172	4.125
37	6615008570828	4.750	2.875	2.8125
38	6615008690825	4.765	2.880	2.825
39	6615009006853	9.625	4.750	4.875
40	6615009034414	9.625	4.750	6.125
41	6615009336037	9.781	5.750	6.125
42	6615009585310	3.750	1.500	1.500
43	6615009732218	9.625	4.750	6.125
44	6615010182177	---	---	---
45	6615010597909	5.258	2.390	2.823

*Dashes (---) Indicate Dimension Not Available.

APPENDIX F

STATISTICAL DATA FOR TAALS AND AIR FREIGHT SORTING

TAALS DATA ANALYSIS

DESCRIPTIVE STATISTICS FOR ITEM WEIGHT IN OUNCES

LABEL WEIGHT (OZ)

Minimum = 4

Maximum = 1792

Range = 1788

Sum = 51824

Mean = 195.562

Median = 105

Modes (Bimodal) = 7 & 112

Variance = 67551.167

Standard deviation = 259.906

Standard error of the mean = 15.995

95 Percent confidence interval around the mean = 164.210 - 226.915

99 Percent confidence interval around the mean = 154.372 - 236.752

* Unbiased estimates of population *

Variance = 67807.043

Standard deviation = 260.398

* Data distribution coefficients *

Skewness = 2.425

Kurtosis = 10.782

Valid cases = 265
Missing cases = 0
Response percent = 100.0 %

TAALS DATA ANALYSIS

DESCRIPTIVE STATISTICS FOR ITEM LENGTH

LENGTH (IN)

Minimum = 6.5

Maximum = 39

Range = 32.5

Sum = 4805

Mean = 18.132

Median = 15.5

Mode = 13.5

Variance = 58.867

Standard deviation = 7.673

Standard error of the mean = 0.472

95 Percent confidence interval around the mean = 17.207 - 19.058

99 Percent confidence interval around the mean = 16.916 - 19.348

* Unbiased estimates of population *

Variance = 59.090

Standard deviation = 7.687

* Data distribution coefficients *

Skewness = 0.615

Kurtosis = 2.441

Valid cases = 265
Missing cases = 0
Response percent = 100.0 %

TAALS DATA ANALYSIS

DESCRIPTIVE STATISTICS FOR ITEM HEIGHT

HEIGHT (IN)

Minimum	=	0
Maximum	=	30.5
Range	=	30.5
Sum	=	2329.42
Mean	=	8.790
Median	=	8.5
Mode	=	6.5
Variance	=	32.973
Standard deviation	=	5.742
Standard error of the mean	=	0.353
95 Percent confidence interval around the mean	=	8.098 - 9.483
99 Percent confidence interval around the mean	=	7.880 - 9.700

* Unbiased estimates of population *

Variance	=	33.098
Standard deviation	=	5.753

* Data distribution coefficients *

Skewness	=	0.309
Kurtosis	=	2.450

Valid cases = 265
Missing cases = 0
Response percent = 100.0 %

TAALS DATA ANALYSIS

DESCRIPTIVE STATISTICS FOR ITEM WIDTH

WIDTH (IN)

Minimum	=	0
Maximum	=	31.5
Range	=	31.5
Sum	=	3375.5
Mean	=	12.738
Median	=	12
Mode	=	10.5
Variance	=	25.908
Standard deviation	=	5.090
Standard error of the mean	=	0.313
95 Percent confidence interval around the mean	=	12.124 - 13.352
99 Percent confidence interval around the mean	=	11.931 - 13.544

* Unbiased estimates of population *

Variance	=	26.006
Standard deviation	=	5.100

* Data distribution coefficients *

Skewness	=	0.577
Kurtosis	=	3.515

Valid cases	=	265
Missing cases	=	0
Response percent	=	100.0 %

DESCRIPTIVE STATISTICS FOR ITEM DIAMETER

DIAMETER (IN)

Minimum	=	0
Maximum	=	11.5
Range	=	11.5
Sum	=	19.5
Mean	=	0.074
Median	=	0
Mode	=	0
Variance	=	0.614
Standard deviation	=	0.764

Standard error of the mean = 0.048

95 Percent confidence interval around the mean = -0.021 - 0.168

99 Percent confidence interval around the mean = -0.051 - 0.198

* Unbiased estimates of population *

Variance	=	0.617
Standard deviation	=	0.785

* Data distribution coefficients *

Skewness	=	12.638
Kurtosis	=	175.163

Valid cases	=	265
Missing cases	=	0
Response percent	=	100.0 %

TAALS DATA ANALYSIS

DESCRIPTIVE STATISTICS FOR LABEL CUBE OF ITEM

LABEL CUBE (IN3)

Minimum	=	.6
Maximum	=	108
Range	=	107.4
Sum	=	7129.4
Mean	=	26.903
Median	=	4.3
Mode	=	1
Variance	=	1035.035
Standard deviation	=	32.172
Standard error of the mean	=	1.980
95 Percent confidence interval around the mean	=	23.023 - 30.784
99 Percent confidence interval around the mean	=	21.805 - 32.002

* Unbiased estimates of population *

Variance	=	1038.955
Standard deviation	=	32.233

* Data distribution coefficients *

Skewness	=	0.679
Kurtosis	=	1.768

Valid cases = 265
Missing cases = 0
Response percent = 100.0 %

TAALS DATA ANALYSIS

FREQUENCY ANALYSIS OF ITEM TYPE

ITEM TYPE	Number	Percent	Cumulative
1 = BOX	198	74.7 %	74.7 %
2 = TUBE	2	0.8 %	75.5 %
3 = BAG	0	0.0 %	75.5 %
4 = FLAT	60	22.6 %	98.1 %
5 = OTHER	5	1.9 %	100.0 %
Total	265	100.0 %	100.0 %

Missing cases = 0
Response percent = 100.0 %

TAALS DATA ANALYSIS

FREQUENCY ANALYSIS OF ITEM SHAPE

SHAPE	Number	Percent	Cumulative
1 = RECTANGULAR	260	98.1 %	98.1 %
2 = CYLINDRICAL	3	1.1 %	99.2 %
3 = OTHER	2	0.8 %	100.0 %
Total	265	100.0 %	100.0 %

Missing cases = 0
Response percent = 100.0 %

TAALS DATA ANALYSIS

FREQUENCY ANALYSIS OF ITEM SOFTNESS

SOFTNESS	Number	Percent	Cumulative
1 = SOFT	37	14.0 %	14.0 %
2 = MODERATE	20	7.5 %	21.5 %
3 = HARD	208	78.5 %	100.0 %
Total	265	100.0 %	100.0 %

Missing cases = 0
Response percent = 100.0 %

TAALS DATA ANALYSIS

FREQUENCY DISTRIBUTION FOR ITEM FLEXIBILITY

FLEXIBILITY	Number	Percent	Cumulative
1 = HIGH	16	6.0 %	6.0 %
2 = MODERATE	36	13.6 %	19.6 %
3 = LOW	213	80.4 %	100.0 %
Total	265	100.0 %	100.0 %

Missing cases = 0
Response percent = 100.0 %

TAALS DATA ANALYSIS

FREQUENCY ANALYSIS OF ITEM PRIORITY

PRIORITY	Number	Percent	Cumulative
1 =	91	34.3 %	34.3 %
2 =	47	17.7 %	52.1 %
3 =	127	47.9 %	100.0 %
Total	265	100.0 %	100.0 %

Missing cases = 0
Response percent = 100.0 %

TAALS DATA ANALYSIS

FREQUENCY ANALYSIS OF MICAP/EXPRESS MARKING

MICAP OR EXPRESS?	Number	Percent	Cumulative
1 = NO	243	91.7 %	91.7 %
2 = YES	22	8.3 %	100.0 %
Total	265	100.0 %	100.0 %

Missing cases = 0
Response percent = 100.0 %

TAALS DATA ANALYSIS

FREQUENCY ANALYSIS OF ITEM TRANSPORTATION MODE

TRANSPORTATION MODE	Number	Percent	Cumulative
1 = 1ST CLASS MAIL	2	0.8 %	0.8 %
2 = UPS	53	20.0 %	20.8 %
3 = 3RD CLASS MAIL	16	6.0 %	26.8 %
4 = 4TH CLASS MAIL	14	5.3 %	32.1 %
5 = PRIORITY MAIL	6	2.3 %	34.3 %
6 = AIR FREIGHT	117	44.2 %	78.5 %
7 = FEDERAL EXPRESS	3	1.1 %	79.6 %
8 = PUROLATOR	4	1.5 %	81.1 %
9 = MOM	8	3.0 %	84.2 %
10 = UNDESIGNATED	40	15.1 %	99.2 %
11 = WEAPON SYSTEMS POUCH	2	0.8 %	100.0 %
Total	265	100.0 %	100.0 %

Missing cases = 0
Response percent = 100.0 %

TAALS DATA ANALYSIS

DESCRIPTIVE STATISTICS OF ITEM WEIGHT FOR AIR FREIGHT

LABEL WEIGHT (OZ)

Minimum	=	4
Maximum	=	1792
Range	=	1788
Sum	=	23307
Mean	=	199.205
Median	=	112
Mode	=	112
Variance	=	71197.360
Standard deviation	=	266.822
Standard error of the mean	=	24.774
95 Percent confidence interval around the mean	=	150.647 - 247.763
99 Percent confidence interval around the mean	=	135.411 - 262.999

* Unbiased estimates of population *

Variance	=	71811.130
Standard deviation	=	267.976

* Data distribution coefficients *

Skewness	=	3.017
Kurtosis	=	15.570

Valid cases	=	117
Missing cases	=	0
Response percent	=	100.0 %

TAALS DATA ANALYSIS

DESCRIPTIVE STATISTICS OF ITEM HEIGHT FOR AIR FREIGHT

HEIGHT (IN)

Minimum = 0

Maximum = 21

Range = 21

Sum = 1038

Mean = 8.872

Median = 8.5

Mode = 6.5

Variance = 29.907

Standard deviation = 5.469

Standard error of the mean = 0.503

95 Percent confidence interval around the mean = 7.877 - 9.867

99 Percent confidence interval around the mean = 7.564 - 10.179

* Unbiased estimates of population *

Variance = 30.164

Standard deviation = 5.492

* Data distribution coefficients *

Skewness = 0.218

Kurtosis = 1.911

Valid cases = 117
Missing cases = 0
Response percent = 100.0 %

TAALS DATA ANALYSIS

DESCRIPTIVE STATISTICS OF ITEM WIDTH FOR AIR FREIGHT

WIDTH (IN)

Minimum = 0

Maximum = 26.5

Range = 26.5

Sum = 1480

Mean = 12.650

Median = 12.5

Mode = 12.5

Variance = 28.283

Standard deviation = 5.318

Standard error of the mean = 0.494

95 Percent confidence interval around the mean = 11.682 - 13.617

99 Percent confidence interval around the mean = 11.378 - 13.921

* Unbiased estimates of population *

Variance = 28.527

Standard deviation = 5.341

* Data distribution coefficients *

Skewness = 0.276

Kurtosis = 2.693

Valid cases = 117
Missing cases = 0
Response percent = 100.0 %

TAALS DATA ANALYSIS

DESCRIPTIVE STATISTICS OF ITEM LENGTH FOR AIR FREIGHT

LENGTH (IN)

Minimum	=	6.5
Maximum	=	39
Range	=	32.5
Sum	=	2166.5
Mean	=	18.517
Median	=	18
Modes (Bimodal)	=	9.5 & 12.5
Variance	=	61.705
Standard deviation	=	7.855
Standard error of the mean	=	0.729
95 Percent confidence interval around the mean	=	17.088 - 19.947
99 Percent confidence interval around the mean	=	16.639 - 20.395

* Unbiased estimates of population *

Variance	=	62.237
Standard deviation	=	7.889

* Data distribution coefficients *

Skewness	=	0.513
Kurtosis	=	2.416

Valid cases	=	117
Missing cases	=	0
Response percent	=	100.0 %

TAALS DATA ANALYSIS

DESCRIPTIVE STATISTICS OF ITEM DIAMETER FOR AIR FREIGHT

DIAMETER (IN)

Minimum = 0

Maximum = 4

Range = 4

Sum = 8

Mean = 0.068

Median = 0

Mode = 0

Variance = 0.269

Standard deviation = 0.518

Standard error of the mean = 0.048

95 Percent confidence interval around the mean = -0.026 - 0.163

99 Percent confidence interval around the mean = -0.056 - 0.192

* Unbiased estimates of population *

Variance = 0.271

Standard deviation = 0.521

* Data distribution coefficients *

Skewness = 7.451

Kurtosis = 56.517

Valid cases = 117
Missing cases = 0
Response percent = 100.0 %

DESCRIPTIVE STATISTICS OF ITEM LABEL CUBE FOR AIR FREIGHT

LABEL CUBE (IN3)

Minimum	=	.6
Maximum	=	9.7
Range	=	9.1
Sum	=	263.5
Mean	=	2.252
Median	=	1
Mode	=	1
Variance	=	3.594
Standard deviation	=	1.896

Standard error of the mean = 0.176

95 Percent confidence interval around the mean = 1.907 - 2.597

99 Percent confidence interval around the mean = 1.799 - 2.705

* Unbiased estimates of population *

Variance	=	3.625
Standard deviation	=	1.904

* Data distribution coefficients *

Skewness	=	1.749
Kurtosis	=	5.771

Valid cases	=	117
Missing cases	=	0
Response percent	=	100.0 %

TAALS DATA ANALYSIS

FREQUENCY ANALYSIS OF ITEM TYPE FOR AIR FREIGHT

ITEM TYPE	Number	Percent	Cumulative
1 = BOX	93	79.5 %	79.5 %
2 = TUBE	2	1.7 %	81.2 %
3 = BAG	0	0.0 %	81.2 %
4 = FLAT	18	15.4 %	96.6 %
5 = OTHER	4	3.4 %	100.0 %
Total	117	100.0 %	100.0 %

Missing cases = 0
Response percent = 100.0 %

TAALS DATA ANALYSIS

FREQUENCY ANALYSIS OF ITEM SHAPE FOR AIR FREIGHT

SHAPE	Number	Percent	Cumulative
1 = RECTANGULAR	113	96.6 %	96.6 %
2 = CYLINDRICAL	2	1.7 %	98.3 %
3 = OTHER	2	1.7 %	100.0 %
Total	117	100.0 %	100.0 %

Missing cases = 0
Response percent = 100.0 %

TAALS DATA ANALYSIS

FREQUENCY ANALYSIS OF ITEM SOFTNESS FOR AIR FREIGHT

SOFTNESS	Number	Percent	Cumulative
1 = SOFT	8	6.8 %	6.8 %
2 = MODERATE	10	8.5 %	15.4 %
3 = HARD	99	84.6 %	100.0 %
Total	117	100.0 %	100.0 %

Missing cases = 0
Response percent = 100.0 %

TAALS DATA ANALYSIS

FREQUENCY ANALYSIS OF ITEM FLEXIBILITY FOR AIR FREIGHT

FLEXIBILITY	Number	Percent	Cumulative
1 = HIGH	5	4.3 %	4.3 %
2 = MODERATE	9	7.7 %	12.0 %
3 = LOW	103	88.0 %	100.0 %
Total	117	100.0 %	100.0 %

Missing cases = 0
Response percent = 100.0 %

TAALS DATA ANALYSIS

FREQUENCY ANALYSIS OF ITEM PRIORITY FOR AIR FREIGHT

PRIORITY	Number	Percent	Cumulative
1 =	53	45.3 %	45.3 %
2 =	30	25.6 %	70.9 %
3 =	34	29.1 %	100.0 %
Total	117	100.0 %	100.0 %

Missing cases = 0
Response percent = 100.0 %

TAALS DATA ANALYSIS

FREQUENCY ANALYSIS OF MICAP/EXPRESS MARKING FOR AIR FREIGHT

MICAP OR EXPRESS?	Number	Percent	Cumulative
1 = NO	108	92.3 %	92.3 %
2 = YES	9	7.7 %	100.0 %
Total	117	100.0 %	100.0 %

Missing cases = 0
Response percent = 100.0 %

Codebook listing - WRALC4

Variable # 1 - TIME (HRS ONLY)
Type = Numeric

Variable # 2 - TIME (MINUTES)
Type = Numeric

Variable # 3 - AM OR PM
Type = Numeric

1=AM
2=PM

Variable # 4 - ITEM TYPE
Type = Numeric

1=BOX
2=TUBE
3=BAG
4=FLAT
5=OTHER

Variable # 5 - SHAPE
Type = Numeric

1=RECTANGULAR
2=CYLINDRICAL
3=OTHER

Variable # 6 - LABEL WEIGHT (LBS)
Type = Numeric

Variable # 7 - LABEL WEIGHT (OZ)
Type = Numeric

Variable # 8 - LENGTH (IN)
Type = Numeric

Variable # 9 - HEIGHT (IN)
Type = Numeric

Variable # 10 - WIDTH (IN)
Type = Numeric

Variable # 11 - DIAMETER (IN)
Type = Numeric

Variable # 12 - LABEL CUBE (IN

Type = Numeric

Variable # 13 - FLEXIBILITY
Type = Numeric

1=HIGH
2=MODERATE
3=LOW

Variable # 14 - SOFTNESS
Type = Numeric

1=SOFT
2=MODERATE
3=HARD

Variable # 15 - TRANSPORTATION MODE
Type = Numeric

1=1ST CLASS MAIL
2=UPS
3=3RD CLASS MAIL
4=4TH CLASS MAIL
5=PRIORITY MAIL
6=AIR FREIGHT
7=FEDERAL EXPRESS
8=PUROLATOR
9=MOM
10=UNDESIGNATED
11=WEAPON SYSTEMS POUCH

Variable # 16 - MICAP OR EXPRESS?
Type = Numeric

1=NO
2=YES

Variable # 17 - PRIORITY
Type = Numeric
